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LONG RANGE SULFUR SUPPLY AND DEMAND MODEL

FINAL REPORT
November, 1971

By

M. H. Farmer
R. R. Bertrand

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Sulfur demand, supply and price are projected to the year 2020. The projections are for use in establishing R&D priorities for recovery of abatement sulfur in marketable and non-marketable forms. The projections are made via a computer model, and permit estimation of the value of abatement sulfur at various times during the forecast period and for various sources and/or quantities of sulfur recovered in useful forms. The model includes the simulation of different abatement schedules and also of additional demand such as might be created by a national stockpile of elemental sulfur. The factors affecting the relative value of sulfur in acid and elemental form are analyzed. The foreign situation is also considered because of its impact on domestic supply/demand/price relationships. The future supply of sulfur will depend increasingly on recovery from fossil fuels. Netbacks will depend on delivery costs to points of net demand and on whether acid or elemental sulfur is recovered.

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FOREWORD

The report on the "Long Range Sulfur Supply and Demand Model" is in three parts.

Part 1 deals with the Model itself, how it was used, and what was concluded. It also suggests how it can be used by the Environmental Protection Agency or others.

Part 2 discusses the relative merits of recovering abatement sulfur in acid and elemental form. The discussion is in the context of the structures of the elemental sulfur and sulfuric acid industries as they exist now, and as they may change during the next three decades.

Part 3 brings together much of the statistical and forecast material in a series of appendices. When using the words "forecast" or "projections", the authors are under no illusions about the hazards of trying to look fifty years into the future. The projections depend on various assumptions, such as the rates at which the economies of the countries of the world will grow. Since there are bound to be different views on such matters, an attempt has been made to analyze or simulate the effects of different assumptions. In this way, the user of the Model should be able to introduce his own assumptions on specific points and to estimate the effects that such judgments would have on the supply and demand situation and on the value of sulfur at various times in the future.

ACKNOWLEDGEMENTS

The projections of fertilizer sulfur demand were provided by Mr. J. H. Sprague, Jr., of Enjay Chemical Company, Inc. However, these projections relate to the forecasts of economic development and population growth made as part of the Sulfur Model and use the same aggregations of countries. It must be pointed out that Enjay's own projections of economic development and population growth may differ from those used in the Model, and that this would lead to different estimates of future demand for fertilizer sulfur.

Assistance was also received from the Corporate Planning Departments of the Humble Oil and Refining Company and of Standard Oil Company (N.J.), and from the Agricultural Chemicals Department of Esso Chemical Company, Inc. Such assistance was in the form of published reference material and other information. These organizations bear no responsibility for the way in which the information has been used; the entire responsibility for this lies with the contractor.

Although only a few of the individual references are to publications of the British Sulphur Corporation and to its journal "Sulphur", these publications were drawn on for much of the historical statistical information. The perspectives gained from articles in "Sulphur" were invaluable. Nevertheless, the contractor is responsible for the interpretations placed on this information.

Finally, the authors wish to thank Mr. Norman Plaks, Project Monitor from the Office of Air Programs, for permitting and encouraging the evolution of the project in such a way that a maximum amount of useful information could be developed within the framework of the contract.

ABBREVIATIONS USED IN REPORT

- Units of Measurement

LT, MT, ST = long ton, metric ton, short ton
SCF, MSCF = standard cubic foot, 1000 SCF
BTU = British Thermal Unit
CE, MTCE = coal equivalent, metric tons of coal equivalent

- Financial

R.O.I. = Return on investment
BT, AT = before taxes, after taxes
DCF = discounted cash flow
B.O.P. = balance of payments

- Price, Value

F.O.B., F.O.R. = free on board, free on rail
F.O.B.V. = free on board value
M.D.V. = maximum delivered value

- Materials

El. S = elemental sulfur
NSP = normal (or single) superphosphate
TSP, DAP = triple superphosphate, diammonium phosphate

- Other

EPA = Environmental Protection Agency
E = estimated
F.W., F.W. ex U.S. = Free World, F.W. excluding U.S.
LP = linear programming
IP = (British) Institute of Petroleum
MITI = (Japanese) Ministry of International Trade and Industry
OGJ = Oil and Gas Journal
OPDR = Oil Paint and Drug Reporter
OECD = Organization for Economic Co-operation and Development

Note: Explanation of terminology is given in the Glossary (Section 9), starting on page 81.

FOREWORD

ACKNOWLEDGMENTS

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1. INTRODUCTION

In its 1970 report on "Abatement of Sulfur Oxide Emissions from Stationary Combustion Sources," the NAE/NRC panel* remarked that:

> "Domestic reserves of sulfur are limited, and consideration should be given to their conservation. It would be desirable to conduct a study of the long range supply and demand situation with regard to the several alternative by-products to aid in establishing priorities for support of control and abatement technology."

This recommendation was given effect in NAPCA** Contract No. EHSD 71-13. The study began on August 21, 1970. Under the guidance of NAPCA's Project Monitor, Mr. Norman Plaks, a progress report was made to the NAE/NRC Ad Hoc Panel on February 9, 1971. Consequent upon this review, the Contract was modified to extend its scope and usefulness.

The Contract, in its revised form, called for projections to the year 2020 of the supply, demand and price of sulfur. These projections would be embodied in a computer model. The model, or correlation charts derived from it, would then be used as a planning tool for establishing R&D priorities, e.g., the relative emphasis that should be given to development of technology for the recovery of abatement sulfur in (a) marketable and (b) non-marketable forms. Included in the model would be the simulation of different abatement schedules, and also of additional demand such as might be created by a national stockpile of elemental sulfur. The foreign situation would be considered because of its impact on domestic supply/demand/price relationships. Finally, the factors affecting the relative values of recovered sulfur in acid and elemental form would be analyzed.

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* Ad Hoc Panel on Control of Sulfur Dioxide from Stationary Combustion Sources, Committee on Air Quality Management, Committees on Pollution Abatement and Control, Division of Engineering, National Research Council, Washington, D.C.

** Now a part of the Environmental Protection Agency.

2. SUMMARY

The events that led up to the current, world oversupply of sulfur and industry's reaction to this situation are summarized in Subsections 2.1 and 2.2. The potential recovery of abatement sulfur and its future impact on the industry is fitted into this context.

Subsection 2.3 indicates the ways in which the Sulfur Model simulates future possibilities, while Subsection 2.4 outlines the basis for the F.O.B. price assumptions used in the computer calculations.

The geographical structure of the Model, including the way in which the U.S. is regionalized, is described in Subsection 2.5. This geographical structure is designed to accommodate the projections of supply and demand.

The remaining Subsections discuss the computer calculations and present the principal conclusions or points that have emerged from the various parts of the study.

2.1 Historical Background

Although sulfur accounts for only 0.06 Wt.% of the earth's crust, it is exceeded in importance to man only by five other elements (C, H, O, N, and P). It is essential to plant life and to human nutrition. In these "uses", there is no substitute for sulfur. However, it is also of ubiquitous importance in the manufacture of other materials and, for the most part, is employed as an "acid value" in such operations. Sulfuric acid is used widely because it is effective and economical. But it is not irreplacable. Many materials could be manufactured with other strong acids or by an entirely different processing route. Thus, the demand for sulfur is primarily the demand for sulfuric acid at economic prices.

Since the Second World War, thare have been two occasions of sulfur shortage, the first in 1951 and the more recent starting in 1965. Prices rose on both occasions, although much more sharply during 1965-68 period. However, the primary factor that alleviated each shortage was quite different. In 1954-55, a new source of Frasch sulfur, Mexican production, entered the market. In 1968, it was sulfur recovered from sour natural gas in Western Canada that swung the balance from world shortage to oversupply.

The difference between the Mexican and the Canadian cases is important because the former involved deliberate production that could be adjusted to match demand. Western Canadian sulfur, on the other hand, is a by-product with output depending on the amount of natural gas processed, i.e. on the demand for natural gas (not on demand for sulfur).

With the wisdom of hindsight, it may be noted that significant recovery of sulfur from Western Canadian gas began in 1961. Furthermore, sulfur from France's Lacq field had entered the market a few years earlier and, by 1961, had already contributed to a world oversupply. However, this did not deter several U.S. producers of Frasch sulfur from reactivating high cost production or developing new production during the period 1963-1969. By now, much of this capacity has been shut down, but not without economic penalty.

The fertilizer industry accounts for about half of the worldwide demand for sulfur, primarily in the form of acid to solubilize phosphate rock (rather than as direct demand for S as a plant nutrient). A tremendous over-expansion of fertilizer manufacuring capacity occurred immediately prior to the collapse of sulfur prices in 1969. In fact, the curtailment of growth in fertilizer demand was one of the factors that contributed to the collapse. The business recession that started in 1969 has affected the industrial demand for sulfur. Thus, during the past few years, total sulfur demand has been on a plateau while supply capability has been increasing. Other factors, besides Canadian sulfur, that have contributed to worldwide oversupply are:

- expansion of pyrite roasting capacity in Europe (as a delayed response to high sulfur prices in the 1967-68 period)
- start-up of a large Frasch operation in West Texas
- expansion of modified Frasch production in Poland
- recovery of elemental S by desulfurization of petroleum (in Japan, M.E., Caribbean and elsewhere).
- increase in level of recovery of acid from smelter gas (particularly in Japan and the U.S.)

In addition, it is generally recognized that air pollution controls have the potential for recovery of sulfur values on a very large scale.

2.2 Current Situation

The starting point for the Sulfur Model is a condition of world oversupply in which the imbalance is caused by by-product supply. Since the demand for the primary product -- energy derived from fossil fuels -- is increasing steadily, there is no immediate prospect of bringing S supply back into balance with demand via the conventional laws of supply and demand. Previous studies (1), (2), (3) have indicated a low elasticity for sulfur demand at low prices (even though high S prices do induce substitution of processes that do not require S). Thus, attempts to stimulate demand for sulfur by cutting prices are not likely to succeed. Demand is expected to expand, but it will do so at a pace set by world economic conditions and not as the consequence of actions that the sulfur producers can initiate.

The supply of by-product sulfur is also related to world economic conditions. Thus, changes in the rate of growth of demand are likely to be paralleled by changes in rates of by-product production. But this compensation is only partial. The type and source of fossil fuel used to supply incremental energy will affect the quantity of recoverable by-product sulfur. For example, current Canadian natural gas production is sixty times as sour as current U.S. production. Hence, incremental production of Canadian gas is contributing significantly to world S supplies whereas incremental U.S. gas production is not.* Of even greater importance, however, is the "overhang" of abatement sulfur. If all of the latter were to be recovered in useful form (in the course of meeting SO_x emission standards), there would be an enormous addition to sulfur supplies. This disturbing prospect is becoming widely recognized. Less obvious, however, is the possibility that much of the "overhang"** will be recovered as a waste product rather than in useful form. Still less obvious is the prospect that if much of the retrofitting of SO_x controls avoids the recovery of S in useful form, then the increment in abatement S potential may be in reasonable balance with the increment in S demand.

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* One effect of importing an additional billion CF/D of Alberta natural gas would be to cause an additional million tons of S to be recovered in Alberta. The same quantity of gas, if it were available from U.S. sources of average S content, would add less than 20,000 tons of S to U.S. supplies.

** i.e., the supply that becomes available though retrofitting of pollution controls to existing plants. At a hypothetical level of zero SO_x emission, the overhang is 11 million long tons of S equivalent. Thus, each 10% reduction of emissions below the 1970 level approximates 1.1 million LT of S equivalent.

Currently, there is a growing oversupply even before abatement sulfur is included in total supplies. In consequence, the initiative has been taken by Alberta's Energy Resources Conservation Board in seeking to arrange export prorationing. In Alberta, this would take the form of stockpiling recovered S beyond an agreed upon market volume. Similar arrangements for stockpiling or restricting deliberate production have been made, or are expected, by France, Mexico and Poland.

The U.S. anti-trust laws may prevent participation by U.S. companies in what has been referred to as a world sulfur cartel(4). In any case, the U.S. Frasch S producers may prefer to strengthen their position in key domestic markets rather than attempting to expand exports. Now that world shipping rates have fallen back to, or below, normal levels, Canadian exporters could undersell the U.S. Frasch producers in foreign markets on a sustained basis. On the other hand, the current Canadian initiative is a step back from price-cutting in recognition of the probability that export prorationing can bring a more satisfactory overall netback on sales. It must be recognized, however, that implementation of this policy would be accompanied by a steady build-up of Canadian stockpiles of recovered S. Therefore, the potential dominance of export markets (with the threat of stockpile liquidation) by Canadian S would increase. It must also be recognized that exports of French, Polish and Mexican sulfur are in the hands of government-controlled companies or agencies. Hence, the prospects for reaching an export prorationing understanding with Canada seem good. Nevertheless, abatement sulfur could disturb any such arrangement even though not a ton of it were to move into export markets. This could happen if an attempt were made to force a large amount of abatement S into the key Florida market. It is considered a certainty that the U.S. Frasch S producers would meet such an attempt by all means possible. It is not projected that this hypothetical situation will occur, but it is one of the possibilities that has been investigated.

2.3 Parametric Cases

Many cases have been calculated by a computer program. Each is a simulation of a hypothetical supply/demand condition rather than being a projection of a condition that is expected to occur. Indeed, the results obtained from some runs make it clear that the simulated condition is unlikely. The individual cases say "with these assumptions, this is likely to occur . . . ." By covering a sufficient range of assumptions, regarding the rate at which abatement sulfur could enter the U.S. market, the user of the Model should be able to investigate a variety of hypotheses. This can be done in an approximate way using the correlation charts, or in a more complete way by rerunning a computer case with a set of new assumptions.

The computer calculations are made with the IBM's "LP MOSS" program. The calculation minimizes the sum of the delivered costs of sulfur received in a number of "regions" from various points of "extra-regional supply". The Model could be simplified (smaller number of supply and demand points) or expanded (larger number of supply and demand points) without any change to the programs used.

2.4 Price Assumptions

The upper limit of the price range for sulfur is determined by:

- The cost, plus return on inventment (R.O.I), of obtaining S values from almost inexhaustible sources such as gypsum.
- The cost of alternate manufacturing processes that avoid the use of sulfur, e.g., nitrophosphate fertilizer processes.

In the short run, S prices may rise above these limits as they have done in the past. In the long run, however, the above alternatives would stabilize prices at levels sufficient to give a competitive return on new capital invested.

The lower limit of sulfur values is indeterminate under conditions of gross oversupply. At a certain point the value of incremental production can become negative. If production is expanded further under these conditions, and if attempts are made to market all such production, the value of all sulfur to many producers could become negative. This is a difficult and unusual concept that requires consideration of the following effects:

- Attempts to market a steadily increasing excess of supply would cause a downward price spiral.
- Very little demand-elasticity at low price levels.
- Inability to cut back production of byproduct S.
- Economic inaccessibility of distant markets because of transportation and marketing costs.

Conditions of gross oversupply may not occur. Nevertheless, the possibility exists. Moreover, the situation could beset an individual producer several years after the start of his own production, i.e. it is a condition that could be brought on by the subsequent actions of other producers. The potential downside risk to a producer of elemental S is easy to estimate since it is simple, and relatively cheap, to stockpile elemental S. The hypothetical downside risk to a producer of abatement acid is substantially greater and less readily predictable.

No cases have been calculated by computer that involve negative F.O.B. prices. Nevertheless, the Model makes it clear that such prices might be necessary in order to sell abatement acid from certain locations at certain times in the future.

2.5 Construction of Sulfur Model

Geographically, the "World Model" for sulfur is divided into individual countries, or groups of countries, that have broad economic and/or political similarities. Figure 1 shows the subdivisions of the world model for sulfur supply, in which the Middle East is a separate unit because of potential for producing sulfur from sour natural gas, by desulfurization of petroleum and from deposits of natural sulfur in Iraq. The world demand model is slightly different in that the Middle East is grouped with other Asia/Pacific countries while Oceania is treated separately because of its high demand for phosphate fertilizers.

The "North American Model" comprises the regions that are active in the computer model. Figure 2 shows that besides true N. American countries (Canada, U.S., Mexico), the model includes the Caribbean region (symbolized by Aruba) and W. Europe (symbolized by Rotterdam). The former is a source of "extra-regional supply" from petroleum desulfurization, while the latter is a region of net demand and, therefore, a target for S exports from the U.S., Canada etc. The U.S. regions in Figure 2 are designated by the names and numbers used in the computer calculations and tables. The actual regions represented by these names are indicated in Figure 3 which is an exploded map of the U.S.

2.6 Supply and Demand Forecasts

Unlike many "long range" projections that may be little more than 10-15 year extrapolations, the Sulfur Model is concerned with the next five decades. For this reason, it was considered necessary to start by making economic projections and then to convert the latter into projections of sulfur supply and demand.

The principal steps in the supply and demand forecasts are listed in Table 1. It will be seen that a major step is to translate projections of economic activity into energy demand. This is necessary because it is from fossil fuels that the greater part of the by-product sulfur is coming, and will continue to come, during the next several decades. In addition, the demand for sulfur, whether it be industrial or fertilizer demand, also correlates with economic activity and economic growth. Consequently, by basing the overall projections on correlations with constant dollar GNP, there is some self-compensation in the net statistics. For example, if economic development is overestimated this would have the effect both of overestimating the potential for sulfur recovery and of demand for sulfur.

Balances of supply minus demand for the "Free World ex U.S." are given in Table 2.* Western Europe and the developing countries (in aggregate) are projected to continue in a net demand position, while Canada and Japan are expected to continue in surplus. Communist countries are also expected

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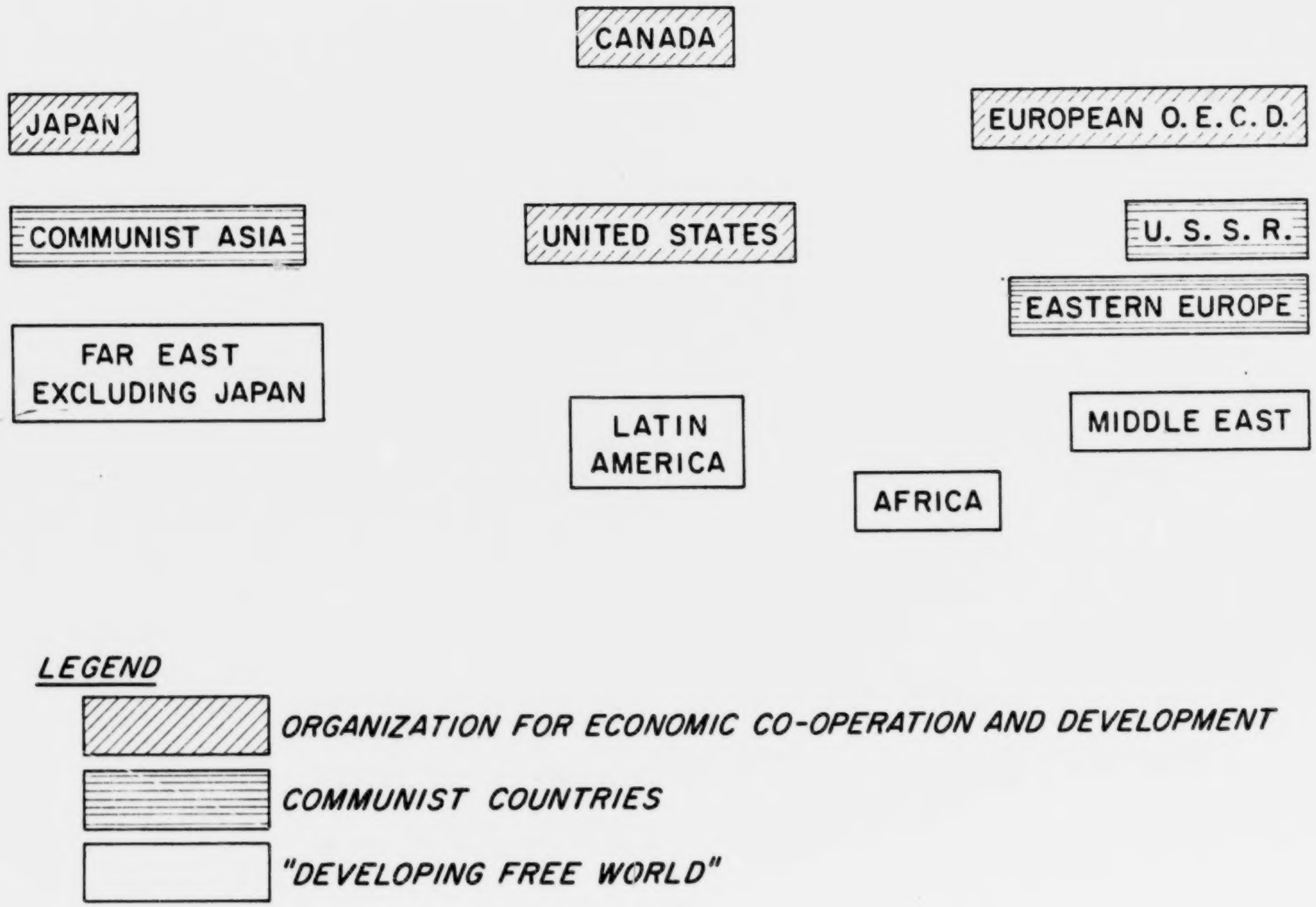
* The statistics are in millions of long tons, because this is the standard unit of the sulfur industry. However, in many parts of the study metric tons are used because this is more usual in energy forecasts.

FIGURE 1

WORLD MODEL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EUROPEAN O.E.C.D.
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FAR EAST EXCLUDING JAPAN
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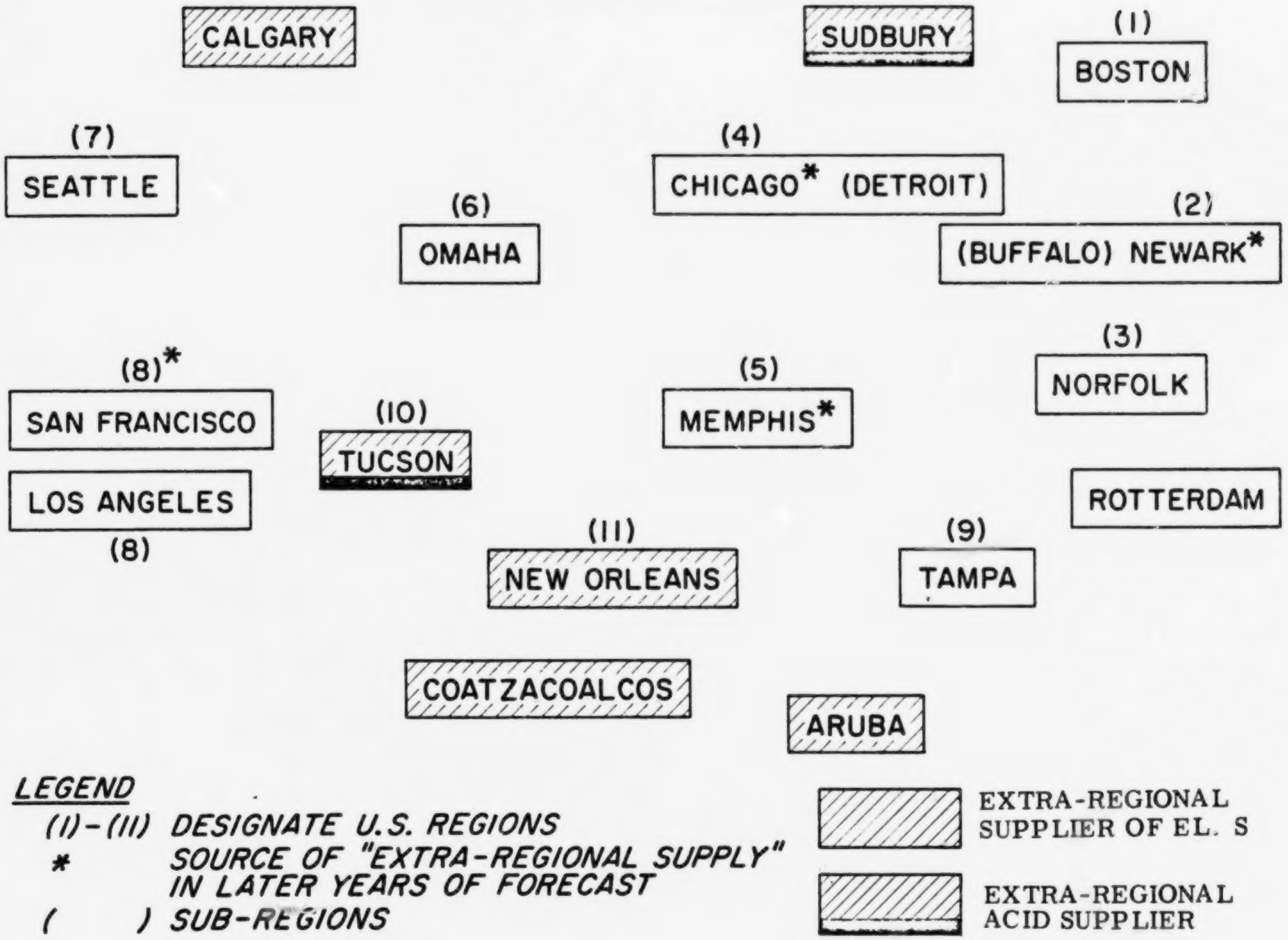
MIDDLE EAST
AFRICA
LEGEND
ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
COMMUNIST COUNTRIES
"DEVELOPING FREE WORLD"

FIGURE 2

NORTH AMERICAN MODEL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NORFOLK
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SAN FRANCISCO
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ROTTERDAM
LOS ANGELES
(8)
(11)
NEW ORLEANS
(9)
TAMPA
COATZACOALCOS
ARUBA
LEGEND
(1)-(11) DESIGNATE U.S. REGIONS
* SOURCE OF "EXTRA-REGIONAL SUPPLY" IN LATER YEARS OF FORECAST
( ) SUB-REGIONS
EXTRA-REGIONAL SUPPLIER OF EL. S
EXTRA-REGIONAL ACID SUPPLIER

FIGURE 3

U.S. REGIONS

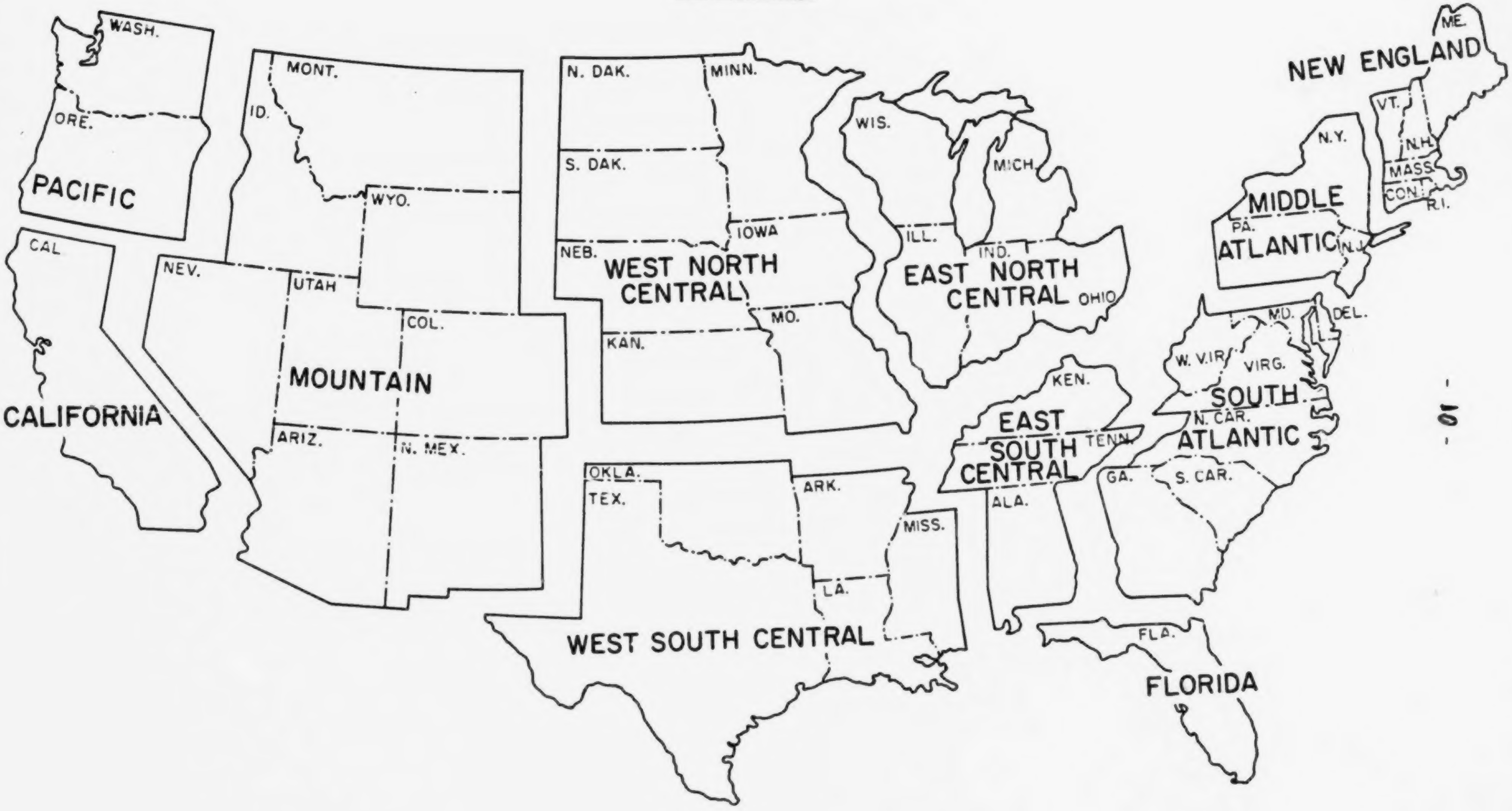
WASH.
ORE.
PACIFIC
CAL
CALIFORNIA
MONT.
ID.
WYO.
NEV.
UTAH
COL.
MOUNTAIN
ARIZ.
N. MEX.
N. DAK.
MINN.
S. DAK.
IOWA
NEB.
WEST NORTH CENTRAL
MO.
KAN.
OKLA.
TEX.
ARK.
LA.
MISS.
WEST SOUTH CENTRAL
WIS.
MICH.
ILL.
IND.
EAST NORTH CENTRAL
OHIO
KEN.
TENN.
EAST SOUTH CENTRAL
ALA.
NEW ENGLAND
ME.
VT.
N.H.
MASS.
CON.
R.I.
N.Y.
MIDDLE ATLANTIC
PA.
N.J.
MD.
DEL.
W. VIR.
VIRG.
SOUTH ATLANTIC
N. CAR.
S. CAR.
GA.
FLA.
FLORIDA

TABLE 1

FORECAST BASIS

- Supply

(1) PROJECTIONS OF : (2) CONSTANT $ GNP
(3) POPULATION

(2) GNP/ENERGY CORRELATION + (2) →(5) ENERGY FORECAST

(6) NUCLEAR AND HYDRO ENERGY FORECASTS

(5) - (6) →(7) FOSSIL FUEL ENERGY FORECAST

(8) BREAKDOWN OF FOSSIL FUEL ENERGY BY SOURCE

(7) & (8) →(9) NATURAL GAS FORECAST
→(10) PETROLEUM FORECAST
→(11) COAL FORECAST

(12) NATURAL GAS SULFUR CONTENT & (9) →(13) NAT. GAS S RECOVERY POTENTIAL

(14) PETROLEUM SULFUR CONTENT & (10) →(15) PETROLEUM S RECOVERY POTENTIAL

(16) COAL SULFUR CONTENT & (11) →(17) COAL S RECOVERY POTENTIAL

(18) % RECOVERY IN USEFUL FORM FROM NATURAL GAS

(19) % RECOVERY IN USEFUL FORM FROM PETROLEUM

(20) % RECOVERY IN USEFUL FORM FROM COAL

(13) & (18) →(21) S RECOVERED FROM NATURAL GAS

(15) & (19) →(22) S RECOVERED FROM PETROLEUM

(17) & (20) →(23) S RECOVERED FROM COAL

(24) PROJECTION OF S RECOVERY FROM SMELTERS, PYRITE AND OTHER SOURCES

(25) PROJECTION OF FRASCH S AVAILABILITY

(21) & (22) & (24) & (25) →(26) TOTAL S SUPPLY (EXCLUDING STOCKPILES)

- Demand

(27) POPULATION & GNP PER CAPITA/FERTILIZER S DEMAND/RELATIONSHIPS

(2) & (3) & (27) → (28) FERTILIZER S DEMAND

(29) GNP/INDUSTRIAL S DEMAND CORRELATION

(2) & (29) → (30) INDUSTRIAL S DEMAND

(28) + (30) → (31) TOTAL S DEMAND

- Supply/Demand Balance

(31) - (21) - (22) - (23) - (24) → (32) NET FOREIGN DEMAND, INCLUDING ABATEMENT S BUT EXCLUDING FRASCH SUPPLY

(31) - (21) - (22) - (24) → (33) U.S. NET REGIONAL DEMAND, EXCLUDING FRASCH SUPPLY AND ABATEMENT S

Note: The symbol & signifies the joint consideration of one factor with another, not a simple arithmetic sum of the factors.

TABLE 2

BALANCES OF SUPPLY MINUS DEMAND FOR REGIONS OF "FREE WORLD ex U.S."*

(MILLION LT)

	1970	1975	1980	1985	1990	2000	2010	2020
Japan	0.9	1.1	1.0	0.7	0.8	1.6	2.1	3.0
Middle E./Far E.	-1.7	-2.7	-2.8	-4.5	-5.3	-7.0	-10.0	-12.6
Africa	-0.3	-0.5	-0.7	-0.8	-1.0	-2.1	-3.4	-4.5
W. Europe	-1.3	-1.8	-1.6	-1.4	-1.8	-3.1	-3.6	-3.9
Latin America	0.7	0.5	-0.1	-0.2	-0.6	-1.7	-3.8	-5.7
Canada	3.6	7.2	10.1	9.8	7.4	3.6	3.8	3.5
Net Position**	1.9	3.8	4.9	3.4	-0.5	-8.7	-14.9	-20.2

* After adjustment for net imports from Communist countries.

** The positive figures in this row imply some combination of:

- Net exports to U.S.
- Stockpiling

The negative figures imply some combination of:

- Net imports from U.S.
- Drawdown of stockpiles
- Alternative ways of satisfying S demand, (e.g., nitrophosphate fertilizer processes)
- Higher than projected level of petroleum desulfurization outside the U.S.

to be in surplus until after 1990. The overall effect is expected to limit U.S. sulfur exports until recovery from W. Canadian sour natural gas has peaked and the associated stockpile of elemental sulfur has been reduced. This should occur by 1990, thereby providing the opportunity for the U.S. to recapture its position as the world's leading exporter of elemental sulfur.

2.7 Computer Calculations

The linear program (LP) calculates the way that each of the "net demand regions" in Figure 2 can secure the necessary supplies at lowest cost from "extra-regional suppliers."

An "extra-regional supplier" is a region that has supplies of sulfur available for shipment to regions in a net demand position. For example, the "New Orleans region" (Okla, Ark, Tex, La, Miss) includes all of U.S. Frasch S production as well as a high concentration of petroleum refining capacity and, thus, is expected to be in a net supply position throughout the forecast period. On the other hand, the "Tampa region" (Fla) is expected to remain in a position of net demand.

The net demand of a particular region is the region's gross demand minus whatever supplies of sulfur are available from within the region. The base case of net demand excludes abatement S from the latter supplies. Other cases include various quantities of abatement S in useful form.* The latter is conceived to reduce the net demand of the pertinent region before the possibility of shipment to another region is considered. Certain regions (Chicago, Memphis, Newark) are permitted to become "extra-regional suppliers" as their potential for recovering abatement S expands.

For reasons given in Section 4.2, abatement S as treated in the Model is confined to what may be recovered by electric utilities. Other actual or potential sources of recovered S are treated in different ways even though they may usually be thought of as abatement S. However, the Model makes an exception in the case of the "Tucson region" (i.e. the Mountain states) where the smelter acid potential is considered to be abatement S for the purpose of the computer calculations.

Other input data used for the LP calculations are:

- F.O.B. price from each extra-regional supplier.
- Quantity of supply available from each extra-regional supplier.
- Transportation cost for each linkage between the extra-regional suppliers and net demand regions.

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* i.e., elemental S or sulfuric acid, but not waste gypsum. Please refer to the glossary in Section 9 for more detailed explanation of terminology.

In addition, certain special features are added:

- upper bounds are placed on the amount of acid that may be supplied to a given region in order to simulate the capacity of the region to accept merchant acid (this capacity increases with time).

- an acid equivalency credit that recognizes that the cost of manufacturing acid is avoided by a customer who purchases acid rather than elemental S.*

- lower bounds on certain supply linkages in order to simulate the effects of marketing systems (e.g. captive terminals in the net demand regions) and captive uses of S by the suppliers (e.g. manufacture of P fertilizers by the Frasch S producers).

In general, the various constraints placed on the Model are removed with time, thereby simulating an evolution of market structure in which the current marketing advantages possessed by certain suppliers would be eroded as new suppliers developed marketing capability.

The output data from the LP program include a matrix of extra-regional suppliers and net demand regions which shows how demand was filled (i.e. who sold to whom), and what the delivered cost was. If no sales were made by a particular supplier to a particular demand region, the required reduction in minimum delivered cost (and, hence, in F.O.B. price) for a sale to occur is printed in the matrix. Other output programs tabulate the sales by and netback to each supplier, and the calculated delivered value of S in each region.

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* The acid equivalency credit changes with time thereby simulating the difference between:

(a) having to shut down existing acid manufacturing capacity in order to be able to purchase merchant acid

and (b) purchasing acid incrementally rather than building new acid manufacturing capacity.

With respect to estimation of the value of abatement S in a particular region, each LP case calculates the value of an incremental unit of supply rather than of supply increments of any size. However, parametric cases involving substantially different quantities of abatement S supply make it possible to obtain value estimates by interpolation. The calculated values are considered to be maxima because new suppliers would have to shave their prices in order to "buy into" an existing market. These maxima are referred to elsewhere as "maximum delivered values" (M.D.V.). As a first approximation, it is postulated that a recoverer of abatement S in elemental form might expect a plant netback of about $10/LT less than the M.D.V. The $10/LT represents a composite of transportation and marketing costs (including price-shaving to buy into the market). Actual transportation and marketing costs are likely to vary greatly from one specific situation to another. Thus, the deduction of $10/LT from M.D.V. to obtain the F.O.B. value (F.O.B.V.) of abatement S should be used with caution.

The words "useful form" are used over and over again to distinquish abatement S recovered in elemental form or as acid from that recovered as a throwaway by-product. Theoretically, a given degree of abatement* could be achieved with no sulfur in useful form (if only throwaway by-products were produced), or with 100% recovery in useful form, or with an infinite number of intermediate cases*. However, what matters in the computer calculations is the quantity of S in useful form and not the percentage that this quantity represents of the total amount abated or of the total abatement potential. This point is crucial to understanding the workings of the Model. It is important to recognize that a given quantity of abatement S in useful form can represent many combinations of abatement levels and percentages in useful form. The calculations of value depend on quantities, but the correlation charts in Sections 4 and 5 provide the connections between (a) levels and percentages of abatement, (b) quantities of S in useful form, and (c) values estimated for what is recovered.

The years 1980 and 2000 have been chosen to illustrate the results of the computer calculations. The choice permits significantly different situations to be contrasted. In 1980, production of W. Canadian sulfur is expected to be at peak levels and backstopped by huge stockpiles, world markets will be under intense supply pressure, and the fitting (and retrofitting) of abatement systems in the U.S. should be beyond the demonstration stage and into widespread use. In contrast, two decades later, W. Canadian S is expected to be a minor factor in world markets, S recovered from petroleum refining will be of major importance while, in the U.S., the policies applied to abatement S in prior years will have determined the shape of the domestic sulfur and sulfuric acid industries and their relationship to world markets.

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* Treated in the Model as the % reduction from the total quantity of SO_x emitted in 1970.

Results that illustrate the conditions projected for the years 1980 and 2000 are given in Tables 3 and 4. The overall sulfur demand of the continental U.S. is summarized in the top segment of each table. This is followed by estimates of demand in two of the most important regions of the Model, Chicago and Tampa. In both cases, sulfur supplies from within the region are deducted to give the net regional demand. These sulfur supplies do not include abatement S in useful form (as defined in p. 13 footnote).

The third segment of each table shows cases that illustrate the effects of different levels of abatement combined with different percentage recoveries in useful form and, hence, different quantities of abatement S in useful form.

The fourth segment of each table shows the net regional demand for the Chicago and Tampa regions, after subtracting the pertinent quantities of abatement S in useful form from the base case of net demand. The reason that the net demand in cases (B) and (C) is the same as in case (A) is that the two former cases make the assumption of no recovery of S in useful form. Even though cases (A), (B) and (C) represent different levels of abatement, they are identical in terms of the assumption that no useful sulfur is recovered. This implies different levels of recovery in throwaway form. However, the latter has no direct effect on the value estimated for abatement sulfur.

The fifth segment of each table shows the estimated value of abatement S corresponding to each quantity of abatement S in useful form. Here, it must be pointed out that, for both years, cases (A), (B) and (C) lie outside the area actually investigated by computer cases. This is because it is considered an unrealistic assumption that no abatement S at all will be recovered in useful form. With no useful abatement S in the year 2000, the M.D.V.'s of $31+ and $30+ (obtained by extrapolation from calculated cases) might be somewhat higher. Additionally, some switching to processes not requiring sulfur would be expected since cases (A), (B) and (C) correspond to a net deficit in supplies for the continental U.S.

It may seem somewhat of a contradiction to have an M.D.V. for abatement S if none is assumed to be recovered in useful form, as in cases (A), (B) and (C). However, the M.D.V. applies, conceptually, to the first units of abatement S that would be recovered in useful form.

For 1980, case (D) suggests an M.D.V. only slightly less than for cases (A) - (C) in both regions. However, a marked difference should be noted for case (E). Here, a marginally lower value is estimated for the Tampa region while an "indeterminately low" value is estimated for the Chicago region. The explanation is that abatement sulfur has hardly changed the net demand of the Tampa region whereas, in case (E), it has produced a condition of gross oversupply in the Chicago region, namely a net demand of minus 0.14 million LT. Because of general conditions of oversupply corresponding to case 1980 E, no extra-regional outlet is envisaged for the Chicago region's surplus of 0.14 million LT.

TABLE 3

ILLUSTRATION OF U.S. SULFUR SITUATION IN 1980

- Continental U.S.

	Million LT
Fertilizer S Demand	7.1
Industrial S Demand	6.7
Total S Demand	13.8

- Demand in Representative Regions

		Chicago	Tampa
	Gross Demand	1.66	3.19
	Regional Supply (excl. Abate. S)	0.59	0.10
(A)	Net Regional Demand	1.07	3.09

- Illustrative Cases of Abatement Supply

	Total SO_x Emitted	% of Abate. S In Useful Form	Quantity of Abate. S In Useful Form (10^6LT)	
(B)	Same as 1970	None	Nil	Nil
(C)	40% Less Than 1970	None	Nil	Nil
(D)	Same as 1970	50	0.49	0.02
(E)	40% Less Than 1970	50	1.21	0.06

- Net Regional Demand After Inclusion of Abate. S in Useful Form (10^6 LT)

(B), (C)	1.07	3.09
(D)	0.58	3.07
(E)	-0.14	3.03

- Estimated Maximum Delivered Value (M.D.V.) for Abate. S ($/LT)

(A), (B), (C)	26	23
(D)	25	22+
(E)	Indeterminately Low	21

Note: Estimates of Value are in 1970 constant dollars.

TABLE 4

ILLUSTRATION OF U.S. SULFUR SITUATION IN 2000

- Continental U.S.

	Million LT
Fertilizer S Demand	11.0
Industrial S Demand	14.2
Total S Demand	25.2

- Demand in Representative Regions (Million LT)

		Chicago	Tampa
	Gross Demand	3.53	4.20
	Regional Supply (excl. Abate. S)	2.92	0.30
(A)	Net Regional Demand	0.61	3.90

- Illustrative Cases of Abatement Supply

	Total SO_x Emitted	% of Abate. S In Useful Form	Quantity of Abate S In Useful Form (10^6LT)	
(B)	Same as 1970	None	Nil	Nil
(C)	40% Less than 1970	None	Nil	Nil
(D)	Same as 1970	50	2.35	0.13
(E)	40% Less than 1970	50	3.50	0.20

- Net Regional Demand After Inclusion of Abate. S in Useful Form (10^6 LT)

(B), (C) Same as Base Case (A)	0.61	3.90
(D)	-1.74	3.77
(E)	-2.89	3.60

- Estimated Maximum Delivered Value (M.D.V.) for Abate. S ($/LT)

(A), (B), (C)	31+	30+
(D)	26	29
(E)	21	28

Note: Estimates of Value are in 1970 constant dollars.

The drop off in estimated M.D.V.'s for the Tampa region is attributable not to the relatively miniscule quantities of abatement S in useful form assumed to be produced within the region but to the corresponding quantities produced in other regions.

For the year 2000, it will be seen that both cases (D) and (E) represent a surplus of supply over demand in the Chicago region. In spite of this, significant M.D.V.'s are estimated for both cases. The explanation is that, in contrast to the 1980 cases, extra-regional outlets for Chicago region sulfur are anticipated, i.e., the Chicago region is expected to be an "extra-regional supplier" by the year 2000. Nevertheless, if the percentage of abatement S recovered in useful form were to be only slightly greater than in case E -- e.g. 60% instead of 50% in useful form -- then the Chicago region would become grossly oversupplied and the estimated value of abatement S in useful form would be indeterminately low.

2.8 Overview of Markets for Abatement Sulfur

Even though many possibilities are considered in the Model, a highly simplified overview of one possibility is shown in Table 5. This is an illustration of the way in which the markets for U.S. abatement S could develop.

(A) is representative of the quantities of abatement S in useful form that may be marketable without creation of a grossly oversupplied condition. (B), (C) and (D) illustrate a possible split of (A) into acid.and elemental S for domestic and export markets.

(E) is the estimated quantity of abatement S that would have to be recovered in some form (useful or throwaway) in order not to exceed the total quantity of SO_x emitted in 1970.

(E) - (A) is the indicated minimum requirement for recovery of S in throwaway form, consistent with the above assumptions. However, it is conceivable that it may not be feasible to develop systems for recovering abatement S economically in elemental form. In this case, the requirement for throwaway systems would be (E) - (B).

At the bottom of Table 5, there are rationalized projections of what might occur. It is assumed that systems for recovering elemental S will not be available in 1975, and will be in an early stage of development in 1980. Subsequently, development is projected to be rapid. Throwaway systems are conceived to be very important initially, then to enter a relatively static period as markets are found for abatement S in useful form, and ultimately to expand once more as the abatement potential exceeds market availability again. The last condition is sensitive to the assumption that coal will be a principal source of gaseous and liquid fuels in the U.S. at the beginning of the 21st century.

TABLE 5

ILLUSTRATIVE CASE OF EVOLUTION OF ABATEMENT SULFUR POTENTIAL

(Million LT of S Equivalent)

	1975	1980	1985	1990	2000	2010
(A) Approx. Market for Abate. S*	0.8	2.4	3.8	4.6	7.5	10.0
(B) of which: Acid (max.)	0.2	0.5	1.3	2.1	3.9	4.8
(C) El. S (domestic)	0.6	1.9	2.5	2.5	1.6	1.6
(D) El. S. (export)	--	--	--	--	2.0	3.6
• Recovery of S Values Required to Limit SO_x Emissions to 1970 Level						
(E)	1.1	1.9	3.0	5.5	10.3	17.5
• Indicated Minimum Requirement for Throwaway Systems						
(E) - (A)	0.3	--	--	0.9	2.8	7.5
• Indicated Minimum Requirement for Throwaway Systems if Recovery of Abatement S in Elemental Form is not Feasible, i.e., (C) = (D) = 0						
(E) - (B)	0.9	1.4	1.7	3.4	6.4	12.7
• Rationalized Projections						
Acid	0.2	0.5	1.2	2.1	3.9	4.8
Elemental S	--	0.2	0.5	1.9	3.5	5.2
Throwaway	0.9	1.2	1.3	1.5	2.9	7.5
-Percentage Basis						
Acid	18	27	40	38	38	28
Elemental S	--	10	17	35	34	30
Throwaway	82	63	43	27	28	42

* Without causing gross oversupply

Note that (A) = (B) + (C) + (D).

Stressing that only one "scenario" is represented, the quantities at the bottom of Table 5 may also be viewed in terms of increments of production during the various time periods:

	1970-75	1975-80	1980-85	1985-90	1990-00	2000-10
Acid	0.2	0.3	0.7	0.9	1.8	0.9
El. S	--	0.2	0.3	1.4	1.6	1.7
Throwaway	0.9	0.3	0.1	0.2	1.4	4.6

Among other things, the above figures suggest the possibility of first and second "generations" of throwaway systems. The first generation would find immediate application, while the second might not be needed for another 15 years. However, the possible alternative of storing elemental S rather than throwing away gypsum is another possibility. Furthermore, if substantial reductions from 1970 emission levels were required, it would be necessary to add all of the associated increment in abatement S either in throwaway form or as stockpiled elemental S.

2.9 Delphi Forecast

Many factors affecting long range projections are not forecastable in a rigorous way and must be dealt with by judgment. Any individual or organization is bound to have certain biases when projecting what may occur in the future. Accordingly, a number of economic, technological and environmental questions were prepared in the format of a Delphi forecast. The questionnaire was put to a group of Japanese "oracles" drawn from the first rank of Japanese industry, universities and official positions. In this way opportunities were provided for obtaining viewpoints quite independent of those of the contractor, and also insights into the future that might be radically different. Exceedingly interesting responses were obtained:

- A progressive decline in economic growth rates is predicted for Japan, the European Economic Community, and the United States. One implication is that rates of increase of energy demand will also decline. If this happens, the potential for recovering sulfur from fossil fuels would be expected to slacken. At the same time, lower economic growth rates imply correspondingly lower rates for growth of industrial S demand.

- Nuclear power is expected to develop rapidly. By the 1990's half of the energy input to electricity generation in industrialized countries is expected to be supplied by nuclear power. However, at the turn of the century, fossil fuels are still expected to be supplying much of the energy input to electricity generation. This is an important point because, theoretically, the ubiquitous use of nuclear power could curtail the use of fossil fuels and, hence, remove the need for controls on SO_x emissions. The implication of the projections by the Japanese oracles is that this situation will not occur until after the year 2000.

- More than half of the sulfur present in fossil fuels consumed in Japan, in 1985, is expected to be removed either by processing the fuel before combustion or by removal of sulfur oxides from combustion gases. More than three quarters of the S that is removed is expected to be recovered in useful form including by-product calcium sulfate (expected to be used in building materials).

- New applications for sulfur and sulfuric acid may account for as much as 15% of total Japanese demand by the year 2000. Almost all of this is expected to be in construction materials of various kinds. Whereas most of the current demand for sulfur is in the form of acid, "new uses" are likely to involve elemental S.

2.10 Principal Conclusions

- World oversupply of sulfur is a virtual certainty for at least another decade. Under these circumstances, the introduction of abatement S into the domestic market will be difficult to accomplish without causing chaos in the market - unless much of the recovery is in the form of a throwaway product.

- By 1990, however, it will be important for the U.S. to be able to recover abatement S in useful form. This would help the U.S. to recapture its position as the world's leading exporter of elemental S. If the sulfur is not recovered in useful form, a re-emergence of processes that do not use S and also of relatively high cost processes for manufacturing acid and/or elemental S from gypsum would both be expected.

- There will not be a market for all the abatement S that might conceivably be recovered in useful form. Attainment of a reasonable sales value for abatement S will depend either on stockpiling elemental S until it is needed or on avoiding the production of more abatement S in useful form than can be absorbed by the market at a given time. The quantity will increase with time.

- The domestic market is now essentially an "elemental S market", i.e. the merchanting of acid is less important than the merchanting of elemental S. However, the market for merchant acid is expected to expand progressively during the 1980's and 1990's, i.e. industry structure will change.

- There will be a need for recovery of abatement S in throwaway, acid, and elemental forms. The most immediate need is for economical and effective throwaway systems. The commercial importance of acid recovery systems is expected to increase slowly during the 1970's and more rapidly during the 1980's. If a national stockpile were to be established for elemental S, recovery of abatement S in elemental form would become important during the 1980's; otherwise this need would be deferred until the late 1980's or early 1990's.

- By the 1990's considerable quantities of elemental S will be recovered from petroleum. Most of this recovery will occur in coastal refineries, which will be advantageous from an export standpoint.

- Large quantitites of S are also expected to be recovered from coal gasification or liquefaction. The location of such operations will determine the way in which the recovered S is utilized (or whether it can be utilized at all). However, it is likely that the Chicago region of the Sulfur Model will be the most important center for coal conversion, with plants located on the Illinois Waterway and Ohio River.

- The production of elemental S from W. Canadian sour natural gas is expected to peak soon after 1980. However, a surplus of production over domestic demand will continue for some years and export potential will be maintained by a stockpile of elemental S that is not expected to peak until around 1985-6. Once this peaking occurs, the world balance on a current basis, and excluding U.S. abatement S, is expected to swing from oversupply to net demand (on a current basis). Conceptually, U.S. abatement S can incrementally fill this supply gap.

- In the later years of the forecast, smelters in Eastern Canada are expected to contribute significantly to Canada's export capability. Recovery of elemental S as well as acid is expected.

- Smelters in Arizona are expected to have a continuing excess of S value potential over the quantity that can be marketed unless an economical way of recovering elemental S is developed.

- The projected reversal of the world S balance implies that recovered S will move up to a delivered value of about $35/LT in the 1990's--provided that gross oversupply of abatement S in useful form is avoided. Subtraction of the delivery cost, e.g., from an Illinois Waterway stockpile to Rotterdam, amounting to just over $10/LT on a constant dollar basis, suggests that the netback to a well-located electric utility may be in the range of $20-25/LT compared with about $12-13/LT for the same hypothetical transaction today--and a lower netback still during the next decade when world oversupply is expected to intensify.

REFERENCES

(1) "The Study of the Evolution of the World Sulfur Industry from 1965 to 1975," Battelle Memorial Institute, April 1, 1967.

(2) U.S. Tariff Commission, Hearings on the Competitive Position of U.S. Industries, Statement of Freeport Sulphur Company, December 1, 1970 (page 9):

> "Because the price of sulphur is so minute a part of the cost of the final products sulphur helps to make, the level of sulphur price does not affect the level of consumption."

(3) "Brimstone: The Stone that Burns," Williams Haynes, 1942: "A stubborn fact of the brimstone market is that lower prices do not increase sales . . ."

(4) European Chemical News, 9/24/71, page 5.

3. STRUCTURE OF SUPPLY/DEMAND MODEL

3.1 General Concepts Used in Model

This section begins with a brief discussion of the conventional way in which imbalances between supply and demand are corrected. However, in the case of sulfur, the conventional approach has already been modified by large and growing volumes of byproduct supply. Stockpiles of byproduct sulfur, already large, will grow larger. This, too, will have an impact on the conventional "laws of supply and demand" and the price consequences of these "laws."

Abatement sulfur, i.e., sulfur values recovered from utility stack gases, will have a direct impact in the locations where recovery takes place. However, the indirect impact in other areas may be equally important.

The foregoing definitions of abatement sulfur and of other terms, as they are applied to the Model, are given in Section 9. A brief scanning of this glossary is suggested before proceeding further with Section 3.

3.1.1 Conventional Approach to Supply/Demand Balances

Supply and demand "balances" might more accurately be termed imbalances. The latter tend to be corrected by price adjustments and other changes. However, such corrections may occur over a period of years and may well result in a new form of imbalance rather than in stabilized conditions of supply and demand.

In most industries an oversupply condition is corrected by curtailing production and reducing prices. Conversely, temporary excess of demand over supply is met by liquidation of inventory during the time that new productive capacity is built. Excess demand is also curbed by increased prices. These simple "laws" of supply and demand have broken down in the case of sulfur, because an increasing percentage of total supply is coming from byproduct sources. Thus, the ability to reduce production is limited to non-byproduct (i.e., deliberately produced) sulfur. The term "discretionary production" is also used, but is not wholly apt since there are commercial and economic limits on the degree to which "discretion" can be applied.

All of the discretionary producers of sulfur, e.g., the U.S. Frasch producers, have investments in their production facilities. In many cases, these companies have additional investments in terminals and other distribution facilities as well as in transportation equipment such as liquid sulfur tankers. The investment downstream of the production facility (e.g., Frasch S mine) cannot be fully utilized if production is cut back. The same is true of the investment in the production facilities themselves.

When new investments are being considered, it is normal to think in terms of return on investment (R.O.I.) or discounted cash flow (DCF) return or some other indicator of the profit that can be made on the investment. The goal will vary, depending in part on the risk involved, but in many cases will be in the range of 10% to 20% after taxes (A.T.). Thus, a proposed investment with a calculated R.O.I. of less than 10% A.T. might be considered marginal. However, this does not mean that all investments achieve their profit goals. Business conditions may change and expected profit margins may decline. In consequence, companies may face the decision of either shutting down (or selling) a particular operation or of holding on until conditions improve. If conditions are not expected to improve, a decision may be made to continue the business until cash flow becomes negative.

For the purposes of the sulfur Model, it is assumed that:

a. New deliberate ("discretionary") producers of sulfur values will not enter the business without the prospects of an R.O.I. of at least 10% A.T.

b. Existing deliberate producers will not leave the business until they face a continuing negative cash flow.

Cash flow and R.O.I. are considered to apply to the business as a whole. This includes marketing and takes account of downstream captive operations with which the production of sulfur may be integrated.

3.1.2. Effect of Byproduct Supply

The Model must also take account of byproduct sulfur. In this case, the economic considerations are quite different. The controlling influences are the demand for and profit margin of a main product (e.g., natural gas) from which sulfur must be separated before the product can be marketed. In the limit, this means that byproduct sulfur need have no recoverable value at all and that project economics may be determined entirely by those of a main product such as natural gas, or fuel oil, or copper. Nevertheless, the producers of the main products will try to sell byproduct sulfur as profitably as possible. This may require the stockpiling of a considerable fraction of production (which cannot be controlled because it depends on the demand for another product such as natural gas). Thus, the price at which byproduct sulfur is marketed may have little to do with its cost of production. This may not have been the case when the first plants for recovering sulfur from sour natural gas were built in Alberta, but it is the case now. The pricing basis must always be market oriented. It must recognize the international structure of the sulfur business and the possible repercussions of pricing in such a way that deliberate producers of sulfur could be forced out of business or might seek protection against imports of byproduct sulfur. The producers in the exporting countries must also recognize the impact of their pricing decisions on foreign exchange earnings and royalty payments (e.g., to the Province of Alberta). Thus, the decisions of the Alberta Provincial Government to call for stockpiling of recovered sulfur (which is equivalent to export prorationing)and of the Mexican Government to proration production of Mexican Frasch sulfur may be seen as attempts to stabilize markets.* Nevertheless, pricing is expected to remain competitive in order to:

a. Discourage entry of new deliberate producers of sulfur or sulfur values (e.g., acid from pyrite).

b. Persuade marginal deliberate producers to shut down. In the U.S., this means the continuing closure of high-cost and, probably, medium-cost Frasch mines. In W. Europe, it means the eventual shutdown of less efficient pyrite operations. In Japan, it means the closure of high-cost native sulfur mines.

c. Cause intense competition in those export markets in which all of the principal suppliers compete. The North European market is the most obvious example.

d. Prevent any loss of sales by keeping prices below those needed to encourage replacement of sulfur by other means (e.g., nitrophosphate fertilizer manufacture).

3.1.3 Byproduct Stockpiles

A growing stockpile of recovered sulfur in Alberta will be of special significance because it will overhang future export markets. It will not be in the interests of the Canadian producers to move this sulfur into world markets at prices that would net little or nothing back to Alberta. But it would seem to be in the Canadian producers' interest to keep the major competitive export markets under price pressure in such a way that incremental demand is supplied by Canada (throughout the period in which Canadian supplies greatly exceed local demand).

For the purpose of the Model, cases have been calculated that involve a range of F.O.B. price assumptions. Cases that represent a further penetration of Canadian sulfur in "offshore" markets without further penetration of U.S. markets are regarded as most probable. However, the consequences of other price assumptions are apparent from other cases that have been calculated using the Model.

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* Various descriptions of the Canadian and Mexican prorationing plans have appeared in the press. Page 24 of the 9/24/71 issue of "European Chemical News" gives one of the clearer descriptions of what is planned. Another account is given in Texas Gulf Sulphur's report covering the first 6 months of 1971.

3.1.4 Abatement Sulfur in Useful Form

Introduction of abatement sulfur in useful form, into domestic markets is conceived to restrict the markets available to U.S. Frasch sulfur and to imports from Canada and Mexico. However, because of geography, the impact will not be the same on the principal supply sources. The "geography" involves not only the different costs of transporting sulfur from the principal points of production to the principal points of demand but also the differences in abatement potential in different parts of the U.S. in relation to local demand. Qualitatively, without the need for calculations, it is clear that the abatement potential is greatest in parts of the Midwest that have been penetrated progressively by W. Canadian sulfur. There is also a significant abatement potential in certain E. Coast markets in which Mexican sulfur has been an important factor, and other E. Coast markets in which U.S. Frasch S has an even stronger position. On balance, when the abatement potential begins to be translated into actual supplies, the direct impact should be greater on Canadian and Mexican exports than on U.S. suppliers. However, loss of exports to the U.S. may be expected to sharpen competition with U.S. exports in foreign markets. Thus, an indirect effect of domestic abatement sulfur is likely to be a curtailment of exports of U.S. Frasch sulfur.

3.1.5 Dual Pricing

Although the Model does not use a "dual price" system (one F.O.B. price for exports and a different price for domestic sales) it is easy to estimate what the effects of dual pricing would be. If, for example, abatement supplies in the Midwest were to erode W. Canadian rail exports, compensatory sales of W. Canadian sulfur in N. Europe might be sought at the expense of U.S. exports to the same market. The resulting competition would cause N. European prices to fall. In turn, the netback to the U.S. Gulf (and to Alberta) would be reduced. If the "delivered Tampa" price from the U.S. Gulf were to be maintained, there would be a differential in the netback to the Gulf for Tampa and N. European deliveries. This would be a typical example of dual pricing. However, as the differential began to widen, it would soon be to the advantage of W. Canadian (and Mexican) suppliers to attempt to penetrate the Tampa market, thereby squeezing the U.S. Frasch producers in their prime market. Faced with the alternative of losing export markets or of fighting a price war in the Tampa market, it seems likely that the U.S. Frasch producers would choose the former. This is because the Tampa market has an excellent growth potential as well as being able to provide the best netback per unit of sales. Conceptionally, in decreasing order of importance, markets for U.S. Frasch sulfur as as follows:

a. The Tampa/Bartow area.

b. Gulf Coast markets [almost as important as (a), but somewhat more fragmented.]

c. Markets adjacent to owned terminals on the Mississippi River system and the E. Coast.

d. Markets adjacent to owned terminals in N. Europe.

e. Other U.S. markets.

f. Other foreign markets (e.g., in Asia, Latin America).

Under conditions of world oversupply, it is probable that (e) and (f) would be relinquished if the alternative would be to invite greater competition and price erosion in the other areas. In the case of (c) and (d) the U.S. Frasch producers may be content to keep a reasonable volume moving through their own terminals without aggressive marketing that would invite competition to seek alternative outlet in (a) or (b). Thus, U.S. Frasch producers may be expected to defend (a) and (b)* strenuously and to maintain sales to (c) and (d) long enough for growth in (a) and (b) to be sufficient to support total production at economic levels.

The above conditions are simulated in the Model by cases in which part of the demand** in a specific market is required to be filled from a certain source (such as U.S. Frasch sulfur). Other cases show the hypothetical effect of removing such constraints.

3.1.6 Net Regional Demand

For simplicity the Model, except in a few cases, deals in terms of net regional demand rather than permitting concurrent movements (sales and purchases) in and out of a particular region. In effect, it is assumed that local supplies of elemental sulfur will be absorbed into the local market in preference to extra-regional supplies. The same assumption is made for abatement acid except that a limitation is placed on the fraction of the local market that is permitted to be supplied with either local or extra-regional abatement acid. This limitation is progressively removed with time (i.e., the various time periods of the Model) in simulation of the progressive development of markets for merchant acid. However, each region is treated individually in this respect in order to take account of local situations such as demand for elemental S (rather than acid) by the pulp and paper industry in the Pacific Northwest. The reasoning with regard to markets for abatement acid is given in Part 2 of the report.

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* Except a portion of this market that must, unavoidably, be lost to sulfur recovered from local oil and gas operations.

** In linear programming language a "lower bound" is placed on supply from a certain source. The net demand in a given "region" of the Model is a "fixed bound" that will be equal to or greater than the "lower bound." The Model also employs "upper bounds" on supply which are used to designate the maximum quantity of regional demand that may be supplied in the form of sulfuric acid (in a given year or case).

3.1.7 Maximum Delivered Value

The "netting out" of regional supplies has the effect of reducing the Model to a group of regions with net demand that can be satisfied from a number of extra-regional supply sources. The calculations made by the LP model indicate sales by and netbacks to the extra-regional suppliers under a variety of cost and supply assumptions. At the same time, the Model also indicates the delivered cost of sulfur in a given region. This delivered cost may be considered to be the maximum delivered value of abatement sulfur in the region. The maximum netback to a producer of abatement sulfur would be the maximum delivered value minus the cost of delivery. The latter would, of course, depend on the exact location of the recovery plant in relation to local markets. The Model does not deal with specific cases of this kind, although it could be modified to do so.*

By running (parametric) cases involving varying quantities of abatements sulfur in useful form, the Model permits interpolation of "maximum delivered values" within the range of simulated abatement supply. The LP program calculates the value for an incremental unit of supply rather than for any increment of supply. However, the interpolation approach overcomes this limitation.

The term "maximum delivered value" is used because it is conceived that a new supplier would have to lower his price somewhat in order to "buy into the market." It is anticipated that this would be done in the local market rather than in a distant one.

It is further assumed that local supplies of recovered sulfur enter local markets, i.e., are subtracted from net regional demand. The distinction here is between sulfur recovered from petroleum refining, etc., and "abatement sulfur" recovered from utility plant stack gases. It is recognized that the former need not have any market preference over the latter. The question of preference does not affect the calculation of "maximum delivered value," since it is the overall regional supply/demand situation in relation to the external balance that is conceived to determine regional values. Nevertheless, it is believed that byproduct sulfur from non-utility sources would normally enter local markets ahead of abatement sulfur because:

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* For a complete "solution", the sulfur recovery plant would be designated an "extra-regional supplier" and its potential customer or customers would be considered as "net demand regions." The additional supply and demand regions would then be incorporated into the Model. Transportation costs between the pertinent supply and demand points would be calculated for use in the LP program (which would be unaffected by the incorporation of additional regions). F.O.B. price from the new supplier would then be varied until the new "net demand regions" took all of the new supplies. Running the LP program in this way would indicate not only the F.O.B. value of the new supply but also the effect of the latter on the rest of the participants in the Model. However, an approximate estimate of F.O.B. value could be obtained without any LP runs. All that would be needed would be to subtract the transportation costs from the maximum delivered value already established for the region.

a. U.S. petroleum refiners and natural gas processors already have experience in marketing sulfur (while utility companies do not).

b. Sulfur recovered from refinery H_2S streams is sure to be in useful form, whereas abatement S from utilities need not be in useful form (e.g., it may be waste calcium sulfate).

3.1.8 Abatement Sulfur as an Extra-Regional Source of Supply

Notwithstanding (a) and (b), certain regions that are now in a net demand position are conceived to emerge eventually as major sources of supply, i.e., to become "extra regional suppliers" to other regions of net demand. The Model also permits the extra-regional suppliers to export sulfur to N. Europe. The regions conceived to be eventual suppliers are those that combine a high potential for producing abatement sulfur with favorable logistics for delivering sulfur economically to regions of net demand. Other regions with some potential for extra-regional supply are not expected to realize this potential because of unfavorable logistics.

3.2 The World Model

In the previous section the term "model" was used in reference to the LP computer program, its calculations, and the concepts used in fitting the sulfur supply/demand/price problem into a standard linear programming format. In this section, however, and in the several sections that follow, "model" refers to the geographical structure of sulfur supply and demand.

Because sulfur is an international commodity, supply or demand anywhere can affect the situation in other places. Exports of sulfur from the U.S. or imports into the U.S. affect the domestic balance and have an impact on sulfur prices in regional domestic markets.

The World Model has been developed in two parts: one for supply and another for demand. In turn, each of these parts is made up of several components.

3.2.1 World Demand Model

Total demand for "sulfur in all forms", i.e., for sulfur values, is assumed to be the sum of fertilizer and industrial demand.

Fertilizer S demand is related primarily to the demand for phosphate fertilizers that use sulfuric acid in their manufacture, but also includes ammonium sulfate and other fertilizer materials that contain sulfur. It is important to recognize that there are "non-sulfur routes" to phosphate fertilizers (such as nitrophosphate manufacture or electric furnace reduction of phosphate rock to elemental phosphorus). In the long run, these manufacturing alternatives place an effective ceiling on sulfur prices.

Because it correlates with industrial activity and, hence, with constant dollar GNP, the industrial demand for sulfur was calculated from projections of GNP.

The fertilizer projections were made for:

- United States
- Canada
- Japan
- European O.E.C.D.

Subtotal = O.E.C.D.

- Oceania

Subtotal (incl. O.E.C.D.) = Developed Free World

- Developing Asia
- Africa
- Latin America

Subtotal = Developing Free World

Hence, Free World Total

- Communist Bloc

Hence, World Total.

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* If the sulfur shortage and accompanying high prices of the late 1960's had continued, there is no doubt that a boost would have been given to the construction of new nitrophosphate and electric furnace phosphorus capacity. Plans of this kind were in preparation when the sulfur situation turned to oversupply in 1968.

The industrial demand projections were made for similar groupings of countries in terms of constant dollar GNP, and were then converted to sulfur demand.

Combination of the fertilizer and industrial demand projections gave the total demand for S values on a regionalized world basis.

3.2.2 World Supply Model

The supply projections were made in a similar manner to those for demand, but were more complicated because separate regional estimates were made for:

Frasch sulfur
Sulfur recovered from sour natural gas.
S values from smelting and pyrite roasting
S recovered from petroleum and other sources

For all regions except the U.S., "other sources" included abatement sulfur (primarily from petroleum). For the U.S., the abatement S potential (primarily from combustion of coal) was separated from the estimates of sulfur expected to be recovered from petroleum.

3.2.3 World Supply/Demand Balances

The projections in the two preceding sections were combined to give net balances on a regionalized world basis. Thus, each region such as Japan or W. Europe (European O.E.C.D.) would show either a net demand or a net supply. The balances of the "Free World ex-U.S." were then modified to take account of projected trade in sulfur with Communist countries. Certain other changes were then made to obtain the input data for the "North American Model", as described below.

3.3 The North American Model

The North American Model comprises the U.S. and certain sources of supply and demand outside the U.S. The latter sources are those expected to have a direct impact on the sulfur situation within the U.S.

The external supply sources in the North American Model are:

- Calgary - representing the principal supply point for exports of W. Canadian sour gas S to the Midwest and (via Vancouver) to other countries and other U.S. destinations.

- Sudbury - representing an E. Canadian source of S values, recovered from nickel and copper smelting, for potential export to certain U.S. locations and to N. Europe.
- Coatzacoalcos - representing the principal supply point for exports of Mexican Frasch sulfur.
- Aruba - symbolizing sulfur available from petroleum desulfurization in the Caribbean area (and associated with the demand for low S fuels in tributary U.S. locations).
- Rotterdam - symbolizing net demand for S values in N. Europe.

For the purpose of the computer calculations that involve the North American Model it was necessary to disaggregate the external supply sources listed above from the net regional world balances.

The North American Model treats the U.S. on a regionalized basis as discussed below.

3.4 Regionalized U.S. Model

The U.S. was divided into the eleven regions shown in Table 1. Initially, nine of these regions have net demand for sulfur while two are net suppliers ("extra-regional suppliers" in the terminology of the Model).

In the later years of the Model, some of the regions that initially were in a net demand position were projected to have the potential for becoming "extra-regional suppliers." The projected changes of balance are due, in large measure, to the given regions' potentials for recovering abatement sulfur in useful form. The supply potential of the California region, however, is due to petroleum desulfurization rather than to recovery of S values from utility stack gases.

As for the World Model (Sections 3.2.1 and 3.2.2), internal balances for each U.S. region were obtained from projections of fertilizer and industrial demand for sulfur and of supplies from different sources (including Frasch sulfur in the case of Region No. 11).

TABLE 6

REGIONALIZED U.S. MODEL - INDICATING SUPPLY AND DEMAND REGIONS

Region No.	Regional Name*	Reference Point	States*	Treated As Net Demand Region	 Extra-Regional Supplier
1	New England	Boston	Me., Vt., N.H., Mass., Conn., R.I.	X	
2	Middle Atlantic	Newark	N.Y., N.J., Pa.	X	
3	South Atlantic	Norfolk	Md., Del., W.Va., Va., N.C., S.C., Ga.	X	
4	E.N. Central	Chicago	Ohio, Mich., Ind., Ill., Wis.	X	
5	E.S. Central	Memphis	Ky., Tenn., Ala.	X	
6	W.N. Central	Omaha	Minn., Iowa, Mo., N.D., S.D., Neb., Kan.	X	
7	Pacific N.W.	Seattle	Wash., Oreg.	X	
8	California	Los Angeles	California	X	
9	Florida	Tampa	Florida	X	
10	Mountain	Tucson	Mont., Wyo., Col., N.M., Ida., Utah, Ariz., Nev.		X
11	W.S. Central	New Orleans	Ark., Okla., Tex., La., Miss.		X
• For the Year 1990 and Subsequent Years:					
4	E.N. Central	Chicago	Ohio, Mich., Ind., Ill., Wis.		X
• For the Years 2,010 and 2,020:					
2	Middle Atlantic	Newark	N.Y., N.J., Pa.		X
5	E.S. Central	Memphis	Ky., Tenn., Ala.		X
8	California	San Francisco	California		X

* Some of the regions do not comprise exactly those states usually associated with the regional name, e.g., Mississippi is included above in the W.S. Central region because of its reserves of sour natural gas.

4. PARAMETRIC CASES

Each case for which computer calculations have been made represents a simulation of certain supply, demand and cost assumptions. In forecasting jargon, each case is a "scenario". However, many cases are based on a common set of assumptions, i.e. have the same scenario, except for variation of a single quantity such as supply or demand. The term "parametric cases" has been used to categorize such groups of related cases.

The Environmental Protection Agency required the examination of the effects of sources of "exogenous demand" and "exogenous supply". This was done by investigating cases of "parametric demand" and "parametric supply". The cases were constructed by assuming a proportional effect in each U. S. region of the Model. For example, for a parametric increase of 10% in demand it was assumed that the demand in each region would be increased by 10%. Clearly, other assumptions could have been made but no other rational basis for doing this was apparent. Nevertheless, interpolation between the results calculated by the computer is possible. In consequence, estimation of the effects of non-uniform variations (from region to region) in supply and demand is possible.

Additionally, the effect of a national stockpile of elemental S was examined. Initially, the stockpile was considered to be a source of exogenous demand. However, for reasons given in Section 4.3, the stockpile turns out to be a source of "negative supply".

4.1 Exogenous Demand

The basis of the demand projections is given in Appendix 5. The "base case", before consideration of exogenous sources of demand, is simply the sum of industrial and fertilizer demand for sulfur in a given region. This is the gross regional demand before "netting out" internal regional supplies of sulfur from sources such as petroleum refineries. The latter do not affect gross regional demand*, so the parametric cases are based on the latter.

For the 1975 cases, only a 5% "parametric increase" over the base case was examined. In subsequent years, larger percentage increases were investigated, ranging up to 30% for the year 2020. Although the percentages chosen are arbitrary, they are compatible with the anticipation of new uses for sulfur derived from the Delphi forecast (Appendix 9).

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* Except in so far as the availability of feedstocks etc. may influence the location of petrochemical plants etc. and, hence, the demand for industrial S. However, such considerations were factored into the "base cases" of regional supply and demand.

4.2 Exogenous Supply

As treated in the Model, exogenous supply sources have been investigated in terms of "parametric supply" or, more precisely, "parametric abatement supply in useful form".

The basis of the supply projections is given in Appendix 4. As discussed there, a narrower than conventional definition was applied to "abatement sulfur". Except for one region (comprising the Mountain states that have a large smelter acid potential), "abatement sulfur" refers to S values that may be recoverable by electric utilities. This does not mean that other sources of what, conventionally, would be regarded as abatement S were ignored. It means that the other sources were treated differently than sulfur potentially recoverable by electric utilities. This approach has both advantages and disadvantages that will be explained.

Different types of company can recover sulfur. Some have done it for years while others are not yet in the business. Being in a business during conditions of oversupply may be unpleasant, but entering a business under such conditions is likely to present extreme difficulties. Established companies have all evolved some form of offtake arrangement, possibly direct marketing, possibly an offtake agreement with another marketer, or possibly a variety of different arrangements. In consequence, recovery of incremental quantities of sulfur, e.g. from a petroleum refinery or a sour gas processing plant or acid from a (Eastern) smelter, can be channeled into an existing marketing system. In contrast, a new producer has to force his way into the market under conditions of oversupply and may meet with limited success at least for some time*. Thus, the narrow definition of "abatement sulfur" has the advantage of separating electric utilities as a group with essentially no experience in marketing S values. It also has the advantage of isolating a specific problem rather than entangling it with by-product sulfur in general. The major disadvantage of this approach is that it may be "unfair" to net various regional sources of recovered S out of regional demand before giving electric utilities a chance to supply the regional market, i.e. leaving the utilities with only the net or residual demand in a given region. The "unfairness" may be rationalized in terms of the superior marketing ability of other by-product producers. But this superiority, while real enough, is relative rather than absolute.

It must also be pointed out that the Model deals in an indirect way with general industrial and commercial sources of SO_x. Two rationalizations are offered in support of this approach:

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* For example, there are many published references to the W. Canadian producers of sour gas sulfur "gaining experience in the market". Apparently, the process has required several years and is not yet complete.

(a) The smaller combustion sources of SO_x, that are many in number but small in terms of individual output, will (eventually) gain access to low sulfur fuels*.

(b) Stack gas treatment systems are not likely to be applicable to small installations and, even if they were, the "marketing capability" of such producers is likely to be small.

Having explained the "pecking order" assumed for various sources of recovered sulfur and the special definition of "abatement S", it is possible to introduce a further concept that is of crucial importance to the functioning and understanding of the Model. This is the concept of "useful form". From the standpoint of the computer calculations, it makes no difference whether a certain quantity of useful S represents complete or only partial recovery -- what matters is the quantity itself. Thus, 1000 LT of S in useful form might represent 100% recovery in useful form from a potential of 1000 LT, or it might represent 10% recovery in useful form from a potential of 10,000 LT. The relationships in Figures 4 and 5 are constructed on this basis.

Looking at the correlations for 1975, the straight line designated "0" simulates a condition wherein the _total_ quantity of SO_x _emitted_ by electric utilities would be the same as in 1970. This case implies that some SO_x would be "abated" because the case is predicated on the assumption that the _total_ fuel supply to electric utilities will contain more sulfur in 1975 than in 1970. This is based on the further assumptions that even though the average S content of utility coal will be lower, the quantity of coal consumed will be sufficiently higher to result in a net increase in S fed to electric utility boilers.

The correlation lines marketed "10", "20", "30", "40" refer to 10%, 20%, 30% and 40% reductions in the total quantity of SO_x _emitted_ by electric utilities in 1970. The correlation lines pass through the origin (since if the percentage of S recovered in useful form is zero, then no long tons of S values are recovered in useful form). Aside from this obvious point, greater reductions in S emissions below the 1970 level and increasing _percentages_ in useful form translate into larger _quantities_ (volumes) in useful form.

Looking next at the correlations for 1980 and later years, it will be seen that the % reduction from the 1970 emission level becomes relatively less important than the percentage of recovered S assumed to be in useful form. The reason is that the _differences_ among the various percentage reductions from the 1970 emission level are fixed quantities whereas the abatement potential increases steadily from year to year.

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* Thus, such sulfur appears in the Model as recovery from petroleum refineries, coal gasification plants, etc.

Figures 4 and 5 apply to the continental U. S. However, similar Figures may be constructed for individual regions using the statistics tabulated in Appendix 4.

An understanding of the "useful form" relationship is an essential prerequisite for using the correlation charts presented in Section 5. These charts relate net regional demand to different levels of regional abatement supply in useful form and, thence, to the value of such supply in a given region at a given time.

4.3 National Stockpile of Elemental Sulfur

For many years, farmers have had the option of selling certain agricultural products, e.g. corn, to the Government. Such surpluses have been stockpiled until needed, and with the purpose of putting a floor under producer prices to prevent damage to the industry. In principle, there is no reason why surplus industrial commodities should not be treated in a similar manner. Normally, of course, industrial production can be varied in accordance with demand. Thus, with the exception of stockpiles of certain strategic materials, there has been no need to stockpile raw materials. However, the rate at which by-product sulfur is produced is not related to the demand for sulfur. In fact, the production of abatement S will depend on air pollution regulations. Thus, it might be argued that a surplus of sulfur induced by government regulations should warrant treatment as an (unavoidable) surplus industrial commodity.

Clearly, the establishment of a national stockpile (or stockpiles) of elemental sulfur* would be a matter of governmental and national policy. In discussing the subject, the contractor takes no position pro or con but merely analyzes the effects that a stockpile might be expected to produce.

As treated in the Model, a national stockpile would introduce "negative supply", i.e. it would remove supply from a given region or from all regions with excess supply of recovered abatement S. There is a distinction between "negative supply" and "parametric (increased) demand". The difference occurs because the principal areas of abatement supply do not correspond with the principal areas of S demand. For example, a general increase in abatment supply produces the largest volume of increase in the Chicago region while a general increase in demand has the greatest effects in the Tampa and New Orleans regions.

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* Elemental S is considered to be the only practical form in which S could be stored for extended periods.

Additionally, a national stockpile would permit re-entry of sulfur in later years on the assumption that general oversupply conditions will eventually be corrected.

A further discussion of the different purposes that might be served by a national stockpile is given in Subsection 8.1.3. In concept, a stockpile could serve as a "storeway" alternative to a throwaway by-product, or as a springboard for exports in the late 1980's and subsequently, or as a means of accomplishing both purposes.

4.4 Discussion of Gross Oversupply

The calculated value of abatement S in a given region declines somewhat as the regional abatement supply increases. This expected result is quantified in Section 5. However, once the regional supply equals or exceeds regional demand its value is conceived to fall sharply and, possibly, to become indeterminate.

When a given region becomes oversupplied, the value of abatement sulfur may still be establishable from the calculated delivered value in another region, after making allowance for the inter-regional delivery cost. However, if a concurrent oversupply is occurring in many regions, there is no possibility of achieving a large enough volume of extra-regional sales to avoid the need for stockpiling.

Once stockpiling of abatement sulfur occurs (except in a national stockpile) the value of abatement sulfur in elemental form would be indeterminately low. The value would be the weighted average of the netback obtained for sulfur actually sold and the "value" of the sulfur not sold (i.e., forced into a stockpile). The former value would be low while the latter would be indeterminate, thus leading to an indeterminate weighted average value. The reason for this indeterminacy is that the unsold sulfur would have a value that would be largely a matter of concept (i.e., the value would be arbitrary).

For accounting purposes, inventory may be credited with the same unit value as current sales. This is a normal procedure in businesses where production can be regulated to match sales, and inventory is merely the "working inventory" necessary to support sales. On the other hand, if production can not be controlled and inventory increases steadily, then the "value" that should be assigned to such increases is debatable. A zero value is one possibility. A negative value is possible too, since this would reflect the cost of storage and of transporting the sulfur from the point of recovery to the point of storage. In this case, it might be cheaper to give the sulfur away rather than store it. But, if this were done, it would not be possible to make concurrent commercial sales.

The above considerations lead to two important conclusions:

(a) As long as regional S supply is less than regional demand, the value of an incremental unit of abatement sulfur will approximate the cost of obtaining an incremental unit of supply from an external source (after making due allowance for transportation costs).

(b) If the regional supply of abatement S exceeds regional demand, and cannot find sufficient extra-regional outlets, then the average value of all abatement S in the region becomes indeterminate and close to zero.

The cases calculated by the computer are concerned with the conditions in (a). However, an adequate response to the problem requires also that the circumstances under which (b) would occur be quantified (in terms of regionalized S demand). This quantification has been made outside the LP computer calculations. Stated another way, LP calculations of value have been made where value is conceived to exist. Other calculations have been of the boundaries of regional supply and demand beyond which abatement S would have an indeterminate value or essentially no value at all.

This subject is discussed further in Section 8.1.2.

Figure 4

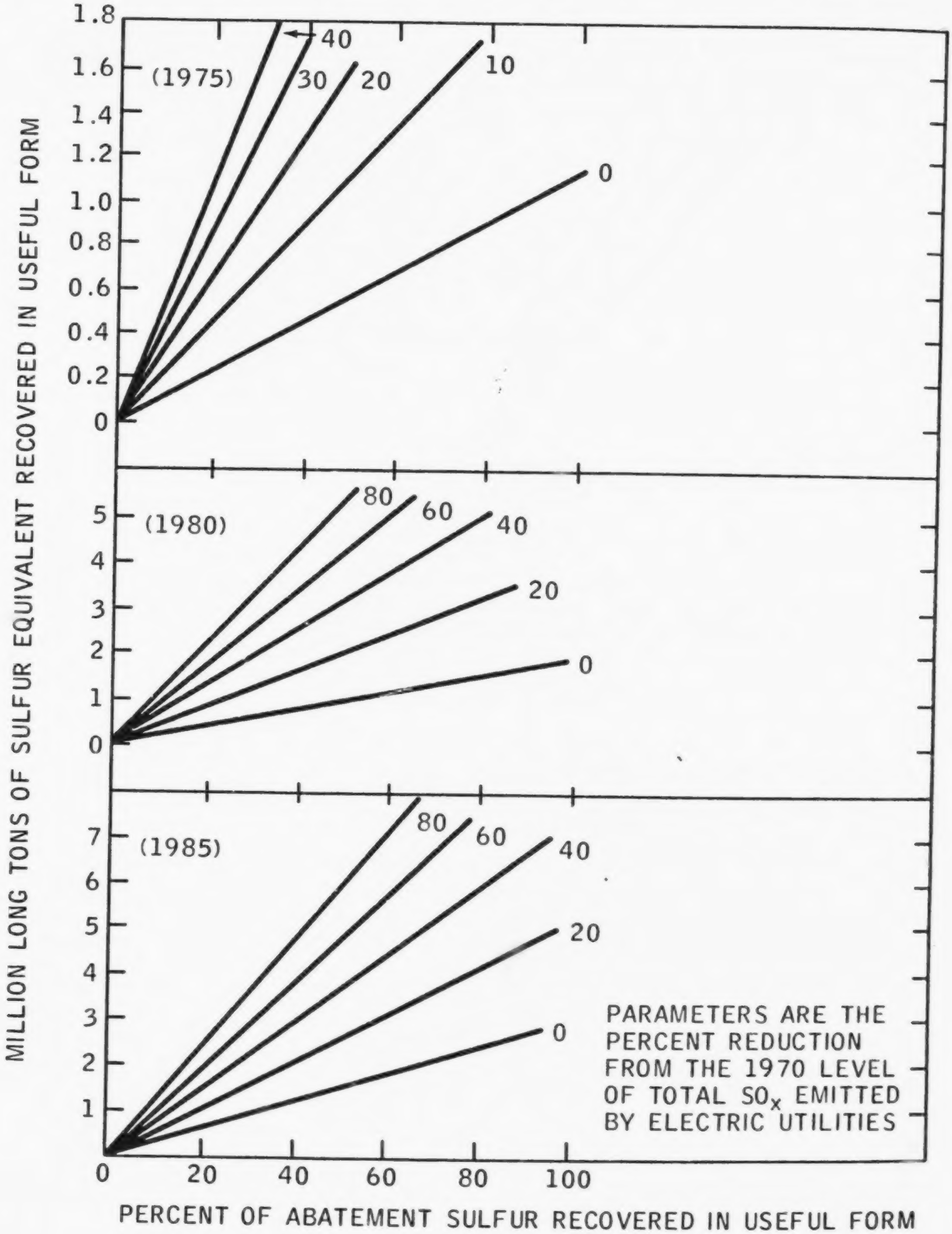
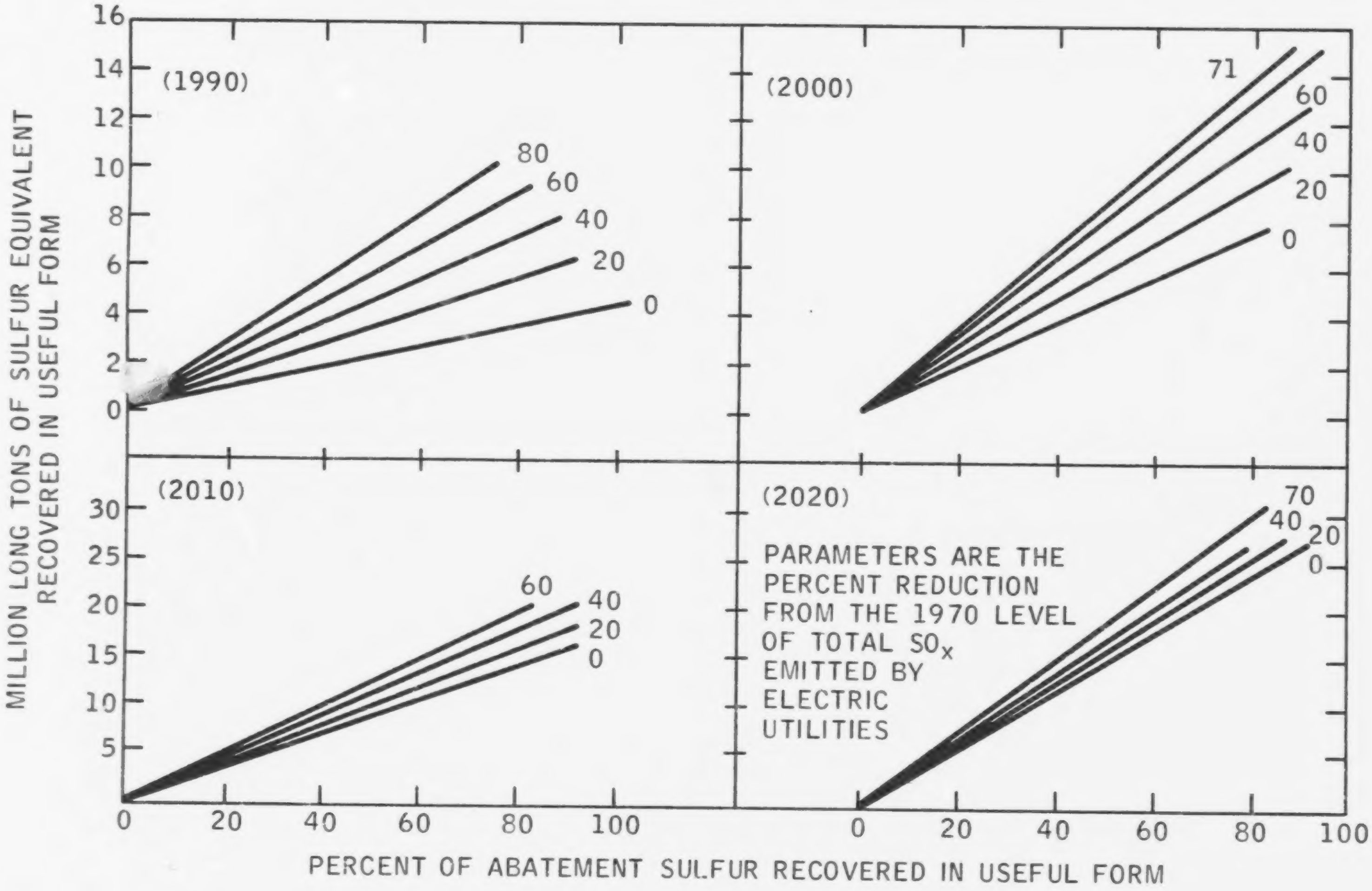

MILLION LONG TONS OF SULFUR EQUIVALENT RECOVERED IN USEFUL FORM
(1975)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
40
30
20
10
0
(1980)
5
4
3
2
1
0
80
60
40
20
0
(1985)
7
6
5
4
3
2
1
80
60
40
20
0
PARAMETERS ARE THE PERCENT REDUCTION FROM THE 1970 LEVEL OF TOTAL SO_x EMITTED BY ELECTRIC UTILITIES
0
20
40
60
80
100
PERCENT OF ABATEMENT SULFUR RECOVERED IN USEFUL FORM

Figure 5



PARAMETERS ARE THE PERCENT REDUCTION FROM THE 1970 LEVEL OF TOTAL SO_x EMITTED BY ELECTRIC UTILITIES

5. COMPUTER CALCULATIONS AND CORRELATION CHARTS

5.1 Input Data

The supply and demand input data are tabulated in Appendix 4, while the cost assumptions are tabulated and discussed in Appendix 6. The structure of Model is covered in Section 3, while details of the computer programs are given in Appendix 7. Additional concepts concerned with parametric cases of supply and demand are explained in Section 4. With the understanding that these data and considerations were used in the computer calculations, it is possible to chart and discuss the principal results of the LP runs*.

5.2 Description of Correlation Charts

The correlation charts in Figures 6-12 cover individual regions and years. The charts indicate:

(a) The variation in net regional demand with increasing regional supply of abatement sulfur in useful form.

(b) The maximum delivered value (M.D.V.) of abatement sulfur corresponding to a given level of supply in useful form.

In addition, a rough estimate of the F.O.B. value (F.O.B.V.) of abatement S in useful form is shown on the charts. In most cases, F.O.B.V. is M.D.V.-10 ($/LT), i.e., it is merely the M.D.V. minus an arbitrary delivery cost of $10/LT**. In a few cases, the F.O.B.V. refers to netback estimated for abatement S shipped to another region. This will be explained further. There are also cases in which it was not possible to estimate either an M.D.V. or F.O.B.V. This, too, will be explained.

No charts were prepared for the year 2020 because the results obtained, while similar to those for 2010, are judged to be too sensitive to the assumptions made.

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* It is impractical to reproduce all of the computer printouts which run to hundreds of pages. However, the information is stored on IBM cards and, with the help of pertinent output programs (described in Appendix 7), can be printed out if needed.

** In several other parts of the report it has been stressed that "average delivery cost" is not a satisfactory concept and that estimates of transportation costs should be made for specific cases. F.O.B.V. is included on the correlation charts for illustrative purposes only, except where a region becomes an extra-regional supplier of abatement S. In this case, F.O.B.V. was calculated by the computer program.

Each figure is a composite of six charts covering the years 1975, 1980, 1985, 1990, 2000 and 2010. This permits the year-to-year projections for a given region to be reviewed without turning pages. However, attention should be paid to the change in scale used in different years.

All of the charts have certain features in common:

- Regional abatement S in useful form is plotted as an abscissa.
- Net regional demand is plotted as an ordinate, with the scale at the left.
- M.D.V. and F.O.B.V. are plotted as ordinates, with a common scale at the right.
- The numbers 0, +5, +10, and +15 refer to parametric demand (as discussed in Section 4).
- All volumes are expressed in million LT of S equivalent.
- All values are expressed in $ per LT of S equivalent.

5.3 Newark Region

The charts may be used to estimate the (changing) value of different quantities of abatement S in useful form. The procedure will be explained by reference to the 1975 chart of Figure 6. If no abatement S were to be recovered in useful form within the region, the net demand of the Newark region would be 0.55 million LT in the base case (or 0.6 million LT with a parametric demand increase of 5%). The M.D.V. corresponding to the base case is $26/LT. This value is obtained by dropping perpendicularly from the supply/demand coordinates (0, 0.55) to the M.D.V. correlation curve and then reading the value off the right hand scale. Similarly, the (arbitrary) F.O.B.V. is $16/LT.

For reasons discussed in Section 4, an increase in the quantity of abatement S in useful form is matched by an equal decrease in net regional demand. On the other hand, an increase in parametric demand would permit an equivalent increase in abatement supply without changing the value relationships*. For example, with 0.1 million LT of abatement supply in useful form, we may locate the point (0.1, 0.5) on the "+5" parametric demand line. The same net demand for the base case has the coordinates (0.05, 0.5), with a corresponding M.D.V. of $24.5/LT. This is also the M.D.V. for the "+5" parametric demand case with coordinates (0.1, 0.5).

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* This is an approximation. Actual computer cases of parametric demand were run. Conceptually, increased demand over the base case might be expected to firm prices more than decreased supply. However, within the Model's accuracy and assumptions, the two conditions are equivalent within a given region.

The "0" parametric demand line (i.e., base case demand) is always used to obtain estimates of M.D.V. With other parametric demand assumptions, the first step is to move along the ordinate of equal net regional demand (i.e., move horizontally to the left) to the "0" parametric demand line and then drop a perpendicular to the M.D.V. correlation curve.

A regional stockpile of abatement S* would act as a "negative supply" of abatement S in useful form. Thus, if there were to be production of 0.2 million LT of abatement S (in elemental form) in the Newark region in 1975, and this same quantity were to be stockpiled then, obviously, the immediate net effect would be the same as if no abatement S in useful form had been produced. Thus, the estimated M.D.V. would be $26/LT. This compares with about $19.5/LT without the stockpile.

It may seem unreasonable that a mere 0.2 million LT of sulfur could depress M.D.V. from $26/LT to $19.5/LT. The explanation is that it has been assumed that the degree of abatement represented by recovery of 0.2 million LT of S in the Newark region would be paralleled in other regions. For the continental U.S. this total increment would be almost 1.5 million LT. It is this increment added to an oversupplied world market that is responsible for a general lowering of prices including those in the Newark region. In the hypothetical case of recovery of 0.2 million LT of S in the Newark region and no recovery anywhere else, it may be judged that M.D.V. for Newark would be higher than $19.5/LT--perhaps close to $25/LT (estimated by using a crude prorating procedure). However, neither the correlation charts nor the computer cases were designed to investigate extremely skewed assumptions.

Looking next at the 1985 portion of Figure 6, it will be seen that the M.D.V. curve begins to turn down sharply as regional net demand approaches zero, i.e., as a regional condition of gross oversupply is approached. It must be pointed out that sharply curving portion of the correlation was not calculated by computer. It has been argued in Section 4 that a (hypothetical) condition could be reached in which the market became saturated, i.e., no incremental production could be sold, and that under such a condition the value of abatement S would be indeterminately low. This is the basis on which M.D.V. and F.O.B.V. curves were bent sharply. Neither the exact shape of the curves nor the point of inflexion has been defined*. In spite of this, the chart is believed to make the important point that up to a volume of about 0.4 million LT (and perhaps a little more) of abatement S, recovered in the Newark region in 1985, would be expected to result in a significant value for the sulfur produced--the M.D.V. would be about $20/LT. If more abatement S were to be recovered in useful form, chaos would be expected unless the increment were stockpiled.

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* Elemental S is assumed.

5.4 Norfolk Region

The curves in Figure 7, for the Norfolk region, are generally similar to those in Figure 6, except that Norfolk is generally conceived to be in a position of net demand. Thus, sharply bending M.D.V. curves are less in evidence. Nevertheless, this condition is possible as indicated in the chart for 1985.

5.5 Chicago Region

The correlations for the Chicago region, in Figure 8, require special comment. This region has a significant demand for sulfur but it has an even greater potential for producing abatement S. Markets for all of this potential cannot be conceived. Hence, all of the M.D.V. and F.O.B.V. curves have sharp downturns. A calculated F.O.B.V. curve is shown for 1990, based upon the assumption that Chicago region sulfur will be moving to extra-regional markets by then. In retrospect, the contrast between the 1985 and 1990 charts suggests that a turn around may not come so quickly. However, a national stockpile in the Chicago region could be a spur to exports and could support the conditions projected in the 1990 chart.

5.6 Memphis Region

Figure 9, for the Memphis region, is similar to Figure 8 except that the absolute volumes of abatement S are much less. This is the basis on which the Chicago region was conceived to have export potential in 1990 while the Memphis region was not assumed to enter export markets until after the turn of the century. Memphis region locations on the Mississippi River system would have a slight advantage in transportation costs over corresponding Chicago region locations with respect to export markets. This might enable the Memphis region to enter export markets sooner than has been assumed. Any increase in the market potential of the Memphis region should be deducted from that of the Chicago region because both are conceived to be in competition for the same extra-regional markets.

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* Nor can it be in advance, since future pricing actions are unpredictable under conditions of a crisis in oversupply with no apparent remedy.

5.7 Omaha Region

Currently, the Omaha region receives most of its supplies from Alberta. While the latter may be displaced with locally produced abatement S, Figure 10 indicates that the absolute demand of the region is small. Thus, the market potential for abatement S appears small, i.e., a condition of oversupply could develop quite readily. This is reflected in the M.D.V. curves. The Omaha region is poorly located with respect to external points of sulfur demand. Although some of the region has access to the Mississippi River system, it is upstream from other regions that have a more powerful abatement potential. Thus, it is inferred that throwaway systems could be of general interest to the region. Low sulfur coal, perhaps after a pretreatment process, is another possibility.

5.8 Tucson Region

The Tucson region is large geographically and completely landlocked. Furthermore, recovery of acid rather than elemental S is probable from copper smelting. In spite of the transportation penalty associated with acid, it is conceivable that some market could be developed in Southern California for the excess potential of the Tucson region*. Some market for merchant acid may develop in the Los Angeles area. This is the basis for the F.O.B.V. calculations plotted in Figure 11. However, the size of the market (if any) is expected to be quite small. Consequently, another solution to the problem of excess S values from Western smelters appears to be required**. If it is economically impractical to recover elemental S from the Western smelters, there is a remote possibility that smelter acid could move to California while elemental S from petroleum refineries in California could be moving into export markets by the end of the century. The hypothesis is flimsy. Nevertheless, it accounts for the higher F.O.B.V. shown for the year 2000 and for the $15/LT F.O.B.V. indicated for 2010. This is equivalent to about $4.50/ST of 100% acid.

5.9 Tampa Region

As discussed elsewhere, the net demand in the Tampa region greatly exceeds its abatement potential. But, as pointed out in Part 2, most of the demand involves captive production of acid from purchased elemental S. The charts in Figure 12 suggest that reasonable F.O.B.V.'s may be possible for local deliveries.

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* The excess potential has its greatest concentration in Arizona.

** Neutralization of SO_2 or acid has been suggested.

of acid in the Tampa/Bartow area*. As mentioned when discussing Figure 6, the downtrend in M.D.V. for the Tampa region with increasing supplies of abatement S in useful form is due to the general level of recovery in the U.S. not to the impact of the Tampa region's own abatement potential.

5.10 Boston Region

No charts have been provided for the Boston region because of its extremely small net demand for sulfur. If oversupply is avoided, the M.D.V. should parallel that in the Newark region.

5.11 Seattle Region

The demand of the Seattle region is predominantly for elemental S. If this small demand were to be met by abatement S, the M.D.V. picture should approximate:

	$/LT
1975	22-25
1980	21-25
1985	20-25
1990	22-26
2000	about 35
2010	about 35

5.12 Los Angeles Region

The supply/demand balance for the Los Angeles region appears likely to depend on relative growth rates for petroleum refining and petrochemicals. As long as supplies of elemental S from petroleum refining are ample, there is unlikely to be a significant market for abatement S. However, as discussed above some outlet for Tucson region acid may develop eventually. Also, once the W. Canadian stockpile of sour gas sulfur is exhausted, California may be in a position to go after Pacific export markets. With these predications, M.D.V.'s for the Los Angeles region are projected to be:

	$/LT
1975	21-24
1980	20-23
1985	18-23
1990	20-24
2000	22-34
2010	22-34

---

* Direct negotiation between potential producers of abatement acid and users of fertilizer acid would seem to be required.

5.13 New Orleans Region

Currently, the New Orleans region is dominated by Frasch sulfur. However, recovery of sulfur from both petroleum and natural gas will increase significantly in volume. Nevertheless, the price of Frasch S is likely to set the value for recovered S in local markets. The range of F.O.B. Frasch prices used in the computer calculations was:

	$/LT
1975	18-23
1980	18-22
1985	16-22
1990	18-23
2000	28-33
2010	28-33

5.14 Markets for Abatement Acid

The concept that markets for merchant acid will develop slowly in the 1970's and more rapidly in the 1980's has been discussed elsewhere (particularly in Part 2). Table 7 is constructed on the basis of this concept combined with the estimates of the net sulfur demand of each region. Thus, Table 7 indicates what is conceived to be the maximum market for abatement acid in each region. The correlation charts may be used to estimate M.D.V. for acid as well as elemental S. In one case of acid, however, Table 7 provides the additional constraint of the maximum quantity of abatement acid assumed to be marketable in a given region. In addition, the "acid equivalency credit" and the relatively higher transportation cost of acid per LT of S equivalent should be taken into account. In spite of the multiple constraints on abatement acid, it may be the best choice (relative to elemental S or a throwaway by-product) provided that all of the constraints can be satisfied.

Figure 6

NEWARK REGION

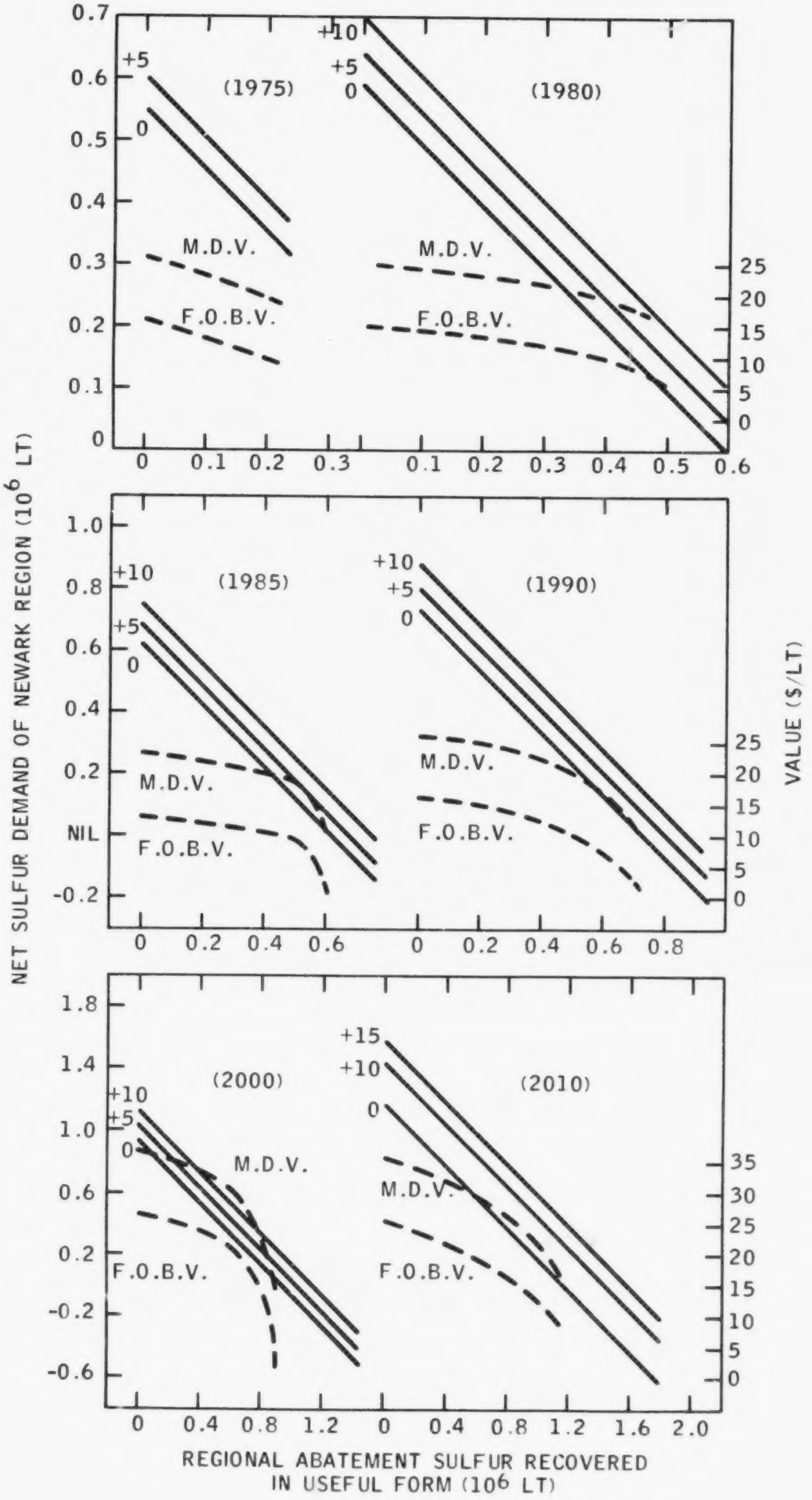

Figure 7

NORFOLK REGION

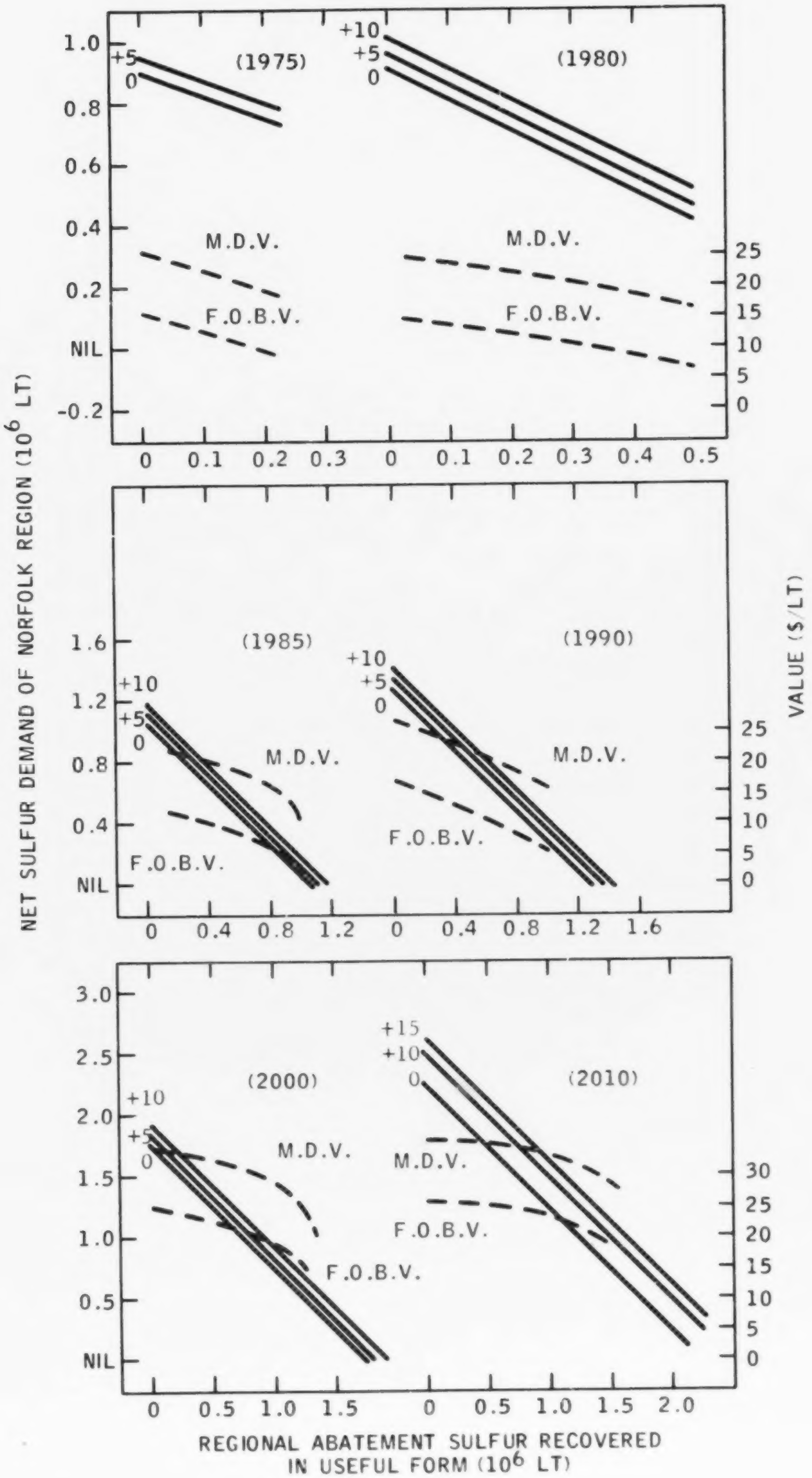

Figure 8

CHICAGO REGION

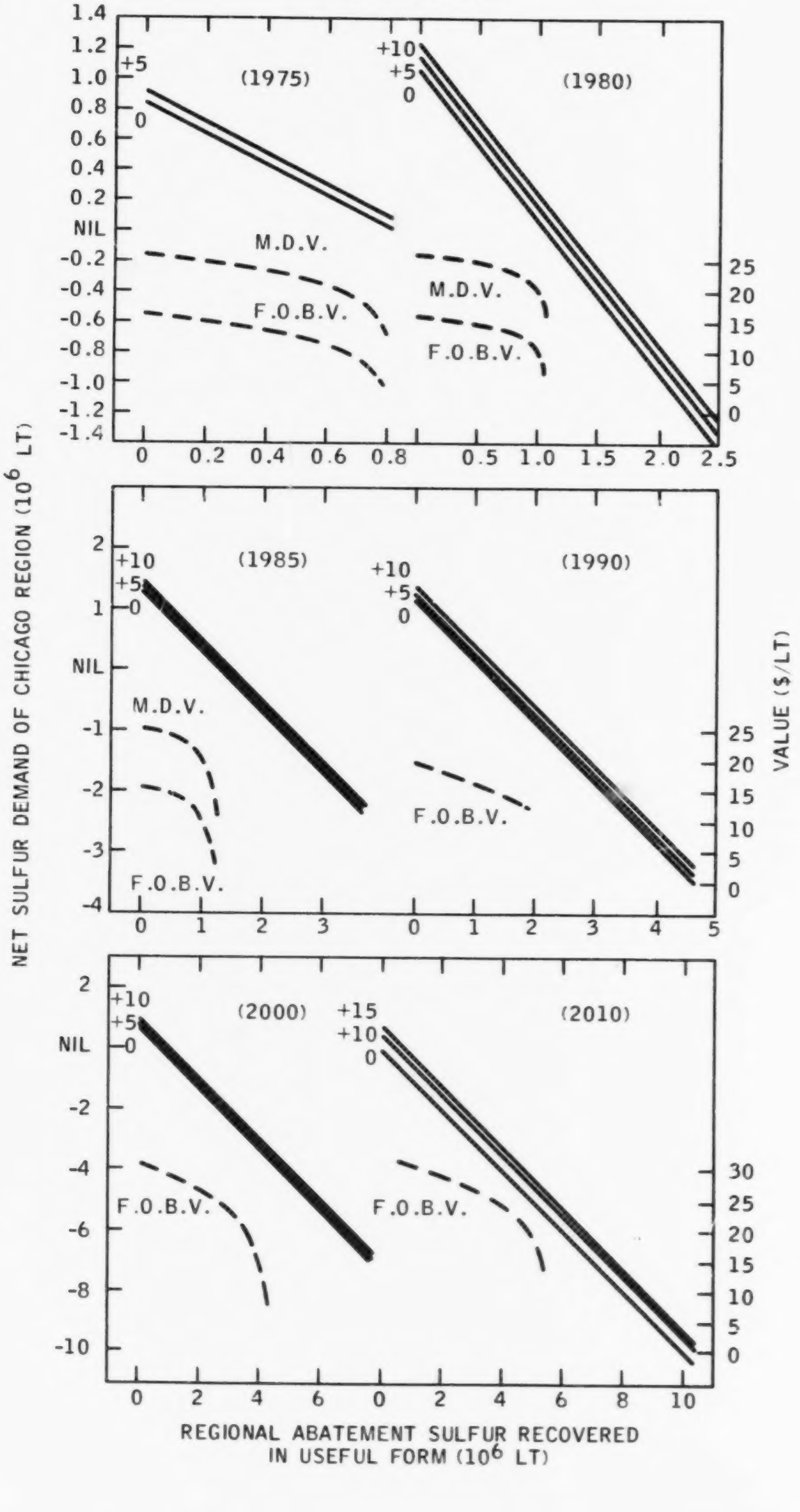

Figure 9

MEMPHIS REGION

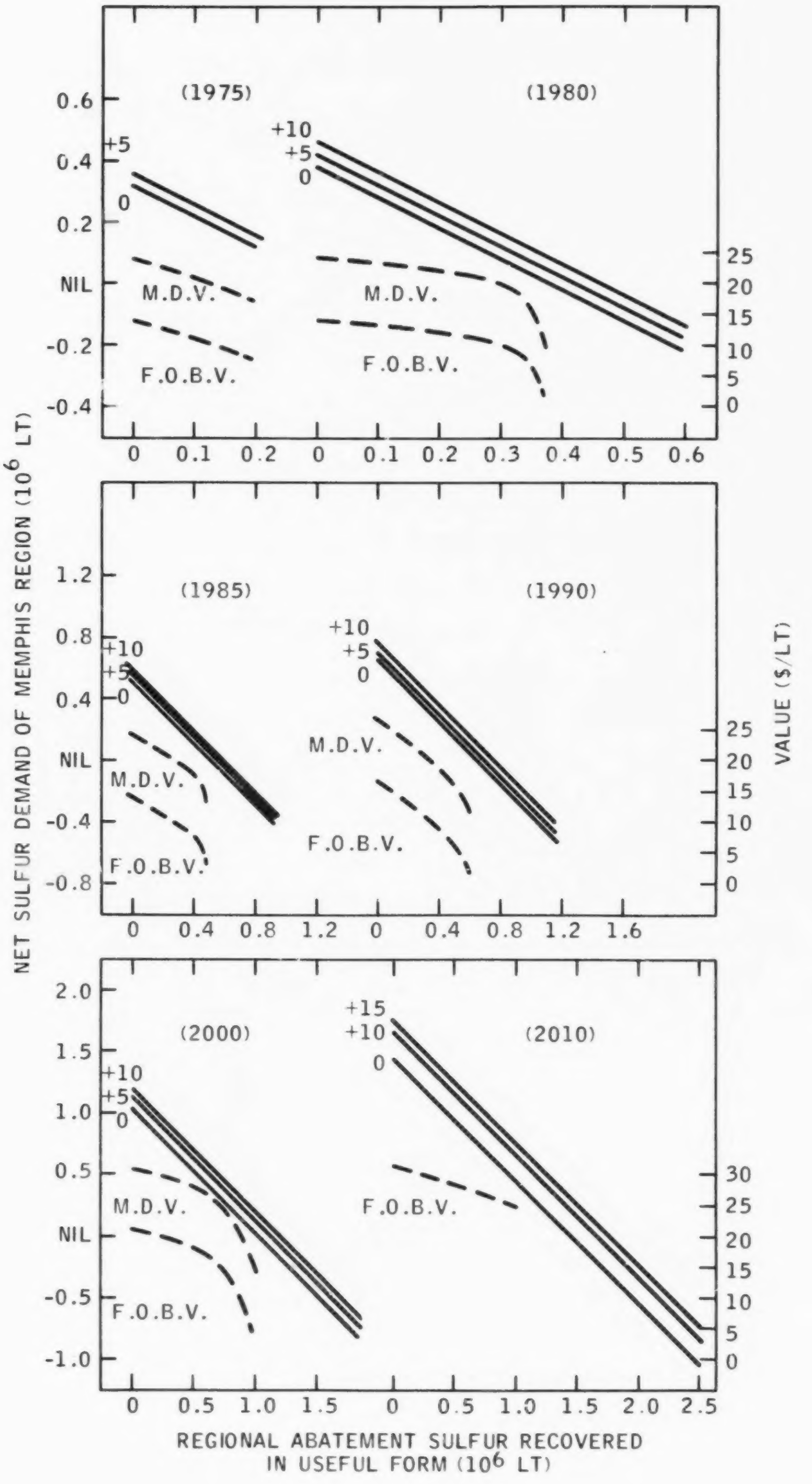

Figure 10

OMAHA REGION

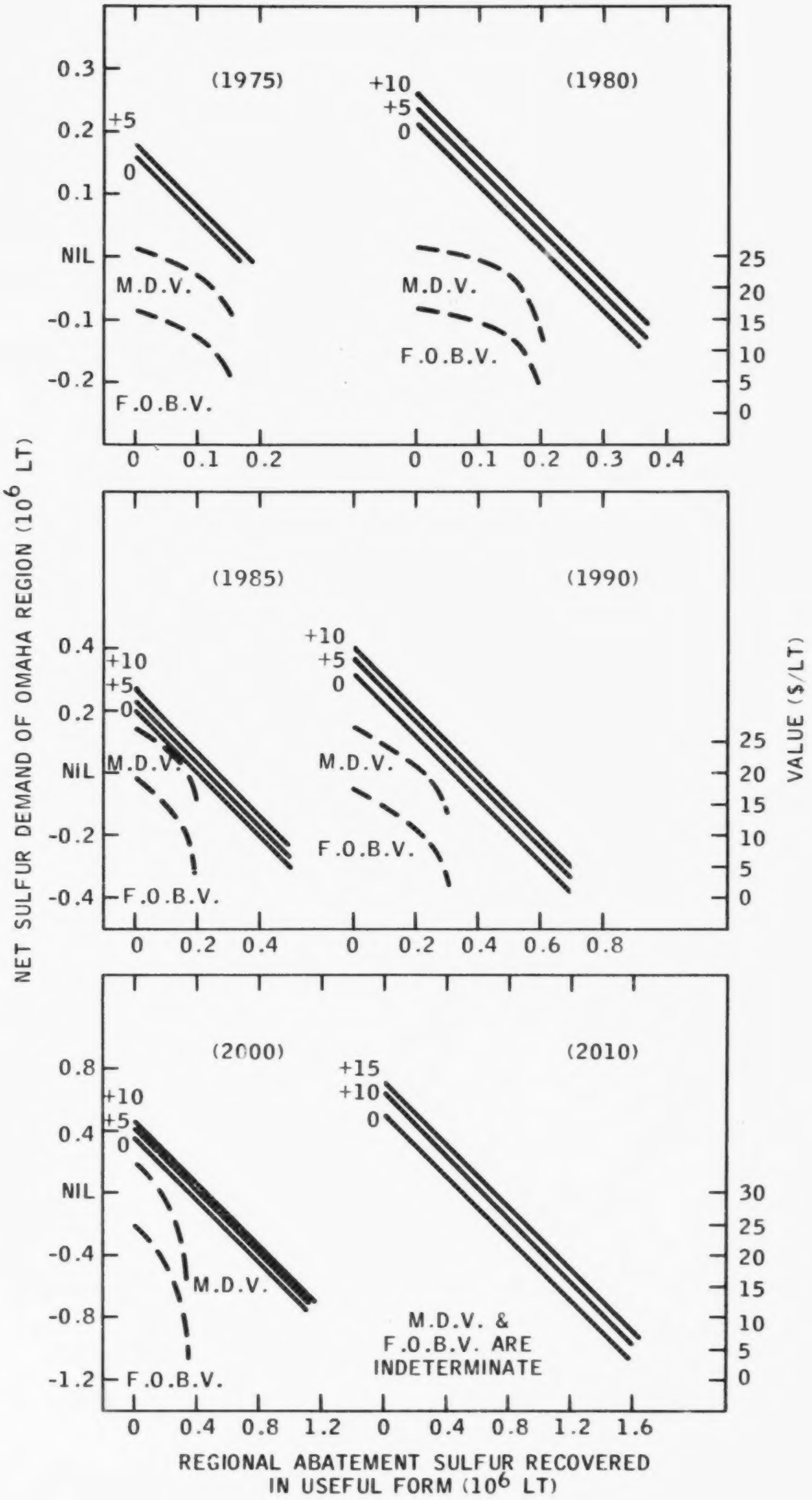

Figure 11

TUCSON REGION

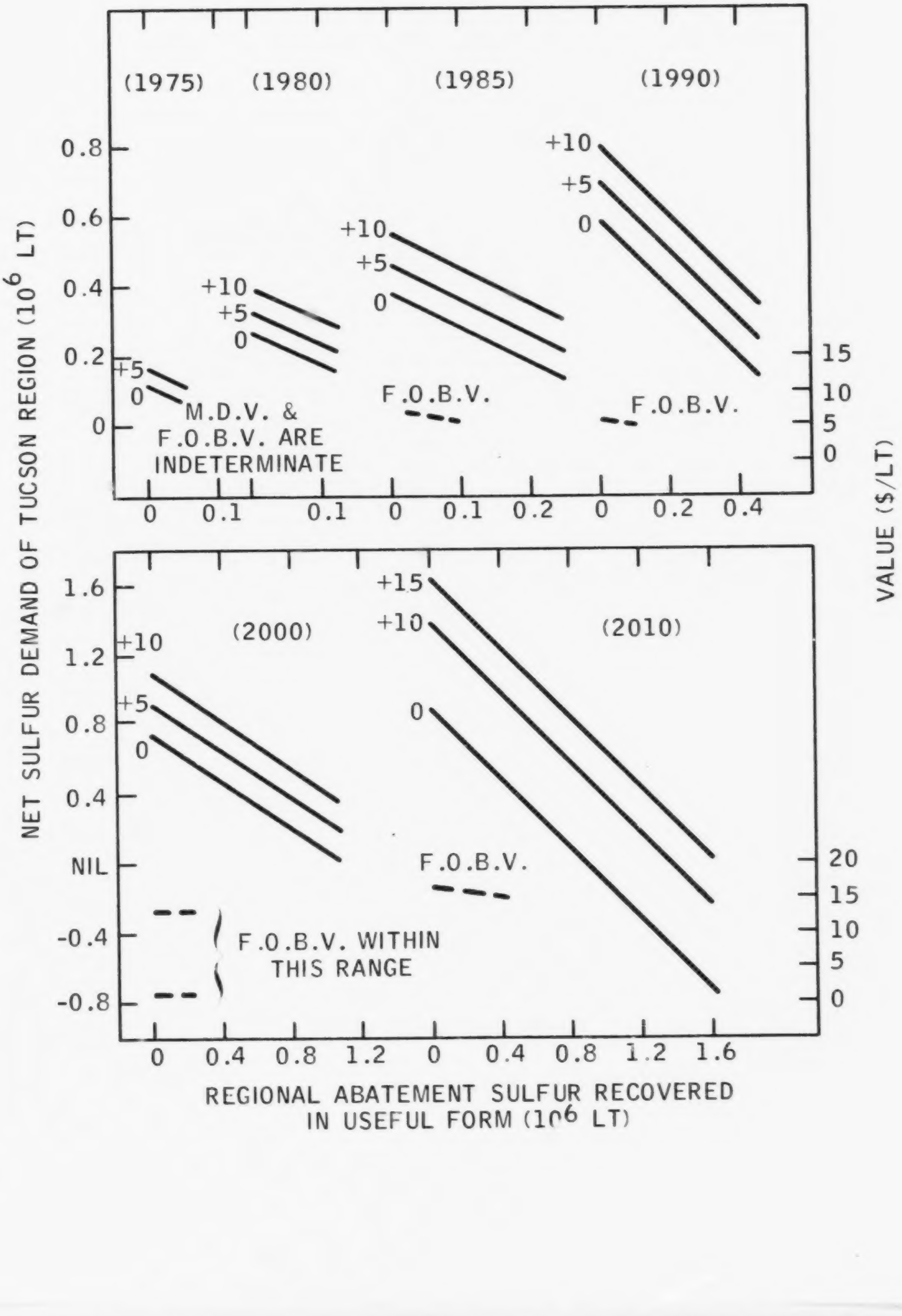

Figure 12

TAMPA REGION

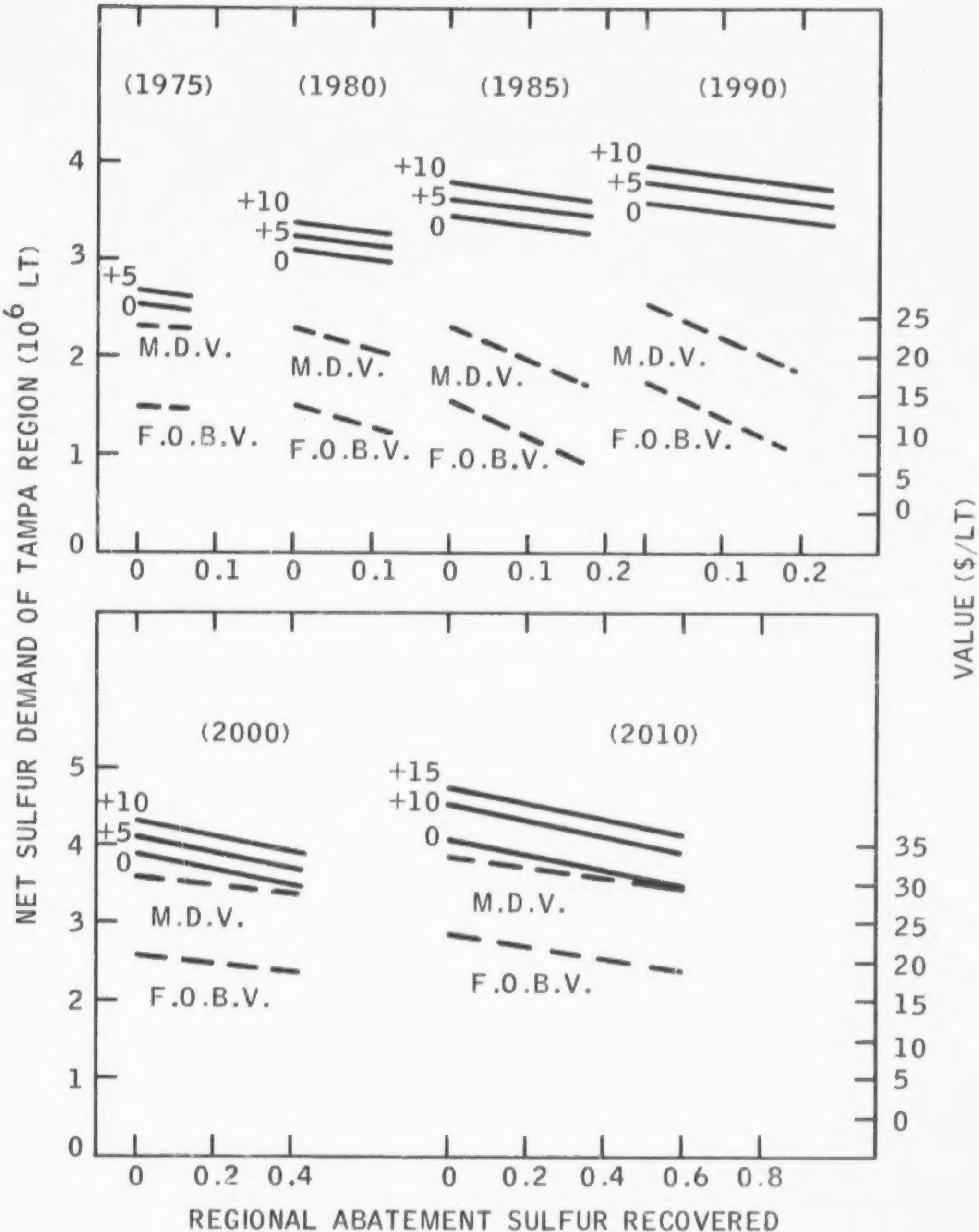

TABLE 7

ESTIMATES OF REGIONAL ABATEMENT ACID POTENTIAL

(Million LT of S Equivalent)

Region	1975	1980	1985	1990	2000	2010	2020
Boston	0.02	0.02	0.03	0.05	0.09	0.14	0.2
Newark	0.09	0.14	0.23	0.54	1.03	1.59	2.2
Norfolk	0.01	0.07	0.26	0.45	0.90	1.44	2.2
Chicago	0.04	0.14	0.50	1.00	1.79	3.26	4.4
Memphis	0.21	0.28	0.37	0.47	0.76	1.14	1.7
Omaha	0.01	0.03	0.07	0.12	0.21	0.47	0.8
Seattle	negl.	negl.	0.02	0.05	0.11	0.33	0.6
Los Angeles	0.03	0.04	0.09	0.17	0.25	0.73	1.4
Tampa	0.13	0.16	0.35	0.38	0.50	0.90	1.4
Tucson	0.21	0.33	0.51	0.81	1.43	2.15	3.0
New Orleans	0.12	0.14	0.33	0.37	0.46	1.20	1.5

Notes:

(1) The above figures apply to abatement acid that might be recovered by electric utilities, except for the Tucson region where additional acid may also come from NFM smelting. In other regions, acid production from smelters has been taken into consideration before making the above estimates.

(2) Estimates are of regional demand. Thus, excess demand in one region might permit additional production in another, e.g., shipment of Tucson acid to Los Angeles.

(3) Estimates are of maximum potential not of marketing probabilities.

(4) Estimates are approximate only (2 decimal places are the result of calculations).

6. SENSITIVITY OF ASSUMPTIONS USED IN REPORT

6.1 General

Throughout the report, note has been taken of the assumptions used in making projections, calculations, interpretations etc. However, in total, the number of assumptions is large and it may not be easy for the reader to make an assessment of those that merely affect details and those that may influence what has been concluded to a major degree. This, then, is not a recapitulation of every assumption. It is an attempt to draw attention to major "sensitivities" in what has been assumed.

6.2 Long Range Projections

Projections for the years 2010 and 2020 are regarded as highly tenuous. One advantage in having made them is that the approach path for prior years is better defined. Another advantage is that certain factors become identified as having critical importance in the later years of the forecast. However, identification of these factors (particularly the quantitative role to be played by nuclear energy during the first part of the 21st century) is merely a first step. Analysis of their probable impact would require considerable additional study.

6.3 Regionalization and Marketing Factors

The Model deals with the U.S. on a regionalized basis. This leads automatically to the questions "What would happen if the regions were subdivided further? What additional information would come to light?" It seems certain that additional insights would be obtained. The "Chicago region", the East North Central states, is an obvious candidate for subdivision. However, for such an extension of the study to be really useful would require concurrent effort on analyzing the structure of local markets for sulfur and sulfuric acid. The factors that affect the marketing of sulfur values have been recognized, but the detailed examination of different marketing strategies (that are, or may be, employed by the various companies involved in the business) would require a large additional effort. The current (false) assumption is that the regions of the Sulfur Model are homogeneous internally. However, what has been done is sufficient to illustrate important dissimilarities among the various regions.

6.4 Recovery Cost/Recovered Value Relationships

The different costs of recovering S in various forms (acid, elemental, throwaway) should be considered along with the estimated values of the various forms. This has not yet been done because the matter of recovery process costs was outside the scope of the contract. The point being made here is that the optimum choice of abatement system depends not merely on the delivered value of a particular form of sulfur, but on: (Delivered Value) minus (Marketing and Transportation Costs) minus (Recovery Process Costs).

6.5 Transportation Costs

Transportation costs are, perhaps, one of the two most important factors affecting the future of the sulfur and sulfuric acid industries. (The other factor is the growing importance of by-product sources of S values, such that these sources will dominate all others long before the end of the century). The very great difficulties of projecting relative shifts in the cost of transportation by rail, barge etc. are discussed in Appendix 6. The assumptions made seem "reasonable", yet this may be because of inadequate knowledge. What appears to be needed is an analysis of the long range, relative costs of different transportation modes combined first with the implications of such costs to the U.S. economy, and then with iterations of the problem that would involve the postulation of different ways in which the relative escalation of rail costs might be avoided. The latter problem is not specific to sulfur; it is fortuitous that the fifty year projections of the Model focus a strong light on it.

6.6 Free Trade

If the U.S. were to impose an import duty or import quota on sulfur, the effect would be to keep some foreign sulfur out of the U.S. market. This would increase the price of U.S. sulfur and, hence, the value of abatement S. There will be a similar consequence if Canadian and other plans for export prorationing are successful. The original "free trade" assumptions specified by the contract were modified slightly to take the "most probable" effects of export prorationing into account. However, a range of possibilities exists. One is that export prorationing will breakdown either immediately or (more likely) if a flood of U.S. abatement S were to divert W. Canadian S from Midwest markets.

6.7 National Energy Policy

The relative incentives and disincentives given to domestic and imported fossil fuels (natural gas, oil, coal, shale) affect the recovery potential for by-product sulfur in the U.S. Once a national energy policy is established, the effects on the sulfur industry could be investigated via the Model. Alternatively, the effects of different policies could be simulated in a series of parametric cases. At the moment, however, only one "reasonable" case has been examined.

It must be recognized that many "energy forecasts" are projections of what could happen unless something else happens first. A purpose of "normative" and "exploratory" forecasts is to influence future events in a favorable way. However the projections in Appendix 2 are not "normative". They have the sole purpose of providing the basis from which sulfur recovery potential can be calculated. This does not make the Model's projections correct, but it does explain why they differ greatly from some of the many other forecasts that have been made.

An article on "Energy, the Economy, and the Environment"* discusses a modelling approach to energy in the U.S. economy and the interrelationships among disparate factors. By coincidence, the approach and rationale used by Professor White has much in common with that used to develop the Sulfur Model except that the latter attempts to place the U.S. economy in a world perspective.

6.8 Short Term Forecasting

The long range model assumes that aberrations in the current situation will disappear and that long term trends will be rational. Short range projections, however, must take account of current aberrations and changes that could occur in the immediate future. Recent changes in spot charter rates and the expectation that export prorationing of sulfur will begin in 1972 are examples of such aberrations.

Short term forecasts are essential to day-to-day business but are not suitable for planning long range research. The Model is concerned with the latter and is not directly applicable to short range forecasting.

6.9 Research Implications

The sensitivity of the research implications that can be drawn from the Model is likely to be much less that the sensitivity of quantitative estimates of sulfur supply and demand. This is because many of the assumptions that could be varied would affect only the level of excess supply rather than the existence of an excess.

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* "Technology Review", October/November 1971, pages 18-31, David C. White, Ford Professor of Engineering, Massachusetts Institute of Technology.

7. CONCLUSIONS

This Section summarizes some of the main projections and conclusions of the study.

7.1 Economic and Demographic Projections

In the year 2000, the U.S. is projected to have a population of 282 million and an average GNP/capita of about $8,000 in 1958 constant dollars. World population is expected to be close to 6.2 billion with an average GNP/capita of $1,500. Thus, the U.S. would have less than 5% of the world's population but approximately 25% of its GNP. Alternate, lower growth rate assumptions for economic development suggest U.S. and world per capita GNP of about $6,900 and $1,250 respectively.

7.2 Energy Projections

At the end of the century, the U.S. is projected to have a total primary energy demand of 6.7 billion metric tons of coal equivalent (MTCE) or 208 x 10^{15} BTU. World demand is projected to be 23.6 billion MTCE or 716 x 10^{15} BTU. These estimates correspond to the higher levels of economic development projected in 7.1.

7.3 Fossil Fuel Sulfur Content

On a worldwide basis, the sulfur content of natural gas reserves averages about 0.7 wt %; crude oil reserves average 1.5 wt % S.

When the S content of all types of coal is corrected to the average heat content of U.S. bituminous coal, the average is also close to 1.5 wt %. U.S. reserves of coal are estimated to contain 18 billion tons of sulfur.

On the average, worldwide, one metric ton of sulfur is associated with each 2.5 billion BTU of primary energy demand supplied by fossil fuels.

7.4 Sulfur Supply

Remaining reserves of U.S. Frasch sulfur are believed to exceed 200 Million LT. At anticipated production rates, these reserves should be adequate for another 40 years or more.

Domestically, by the year 2000, sulfur recovered from U.S. natural gas, from coal used to make synthetic gas, and from petroleum is expected to be about 11.7 million LT, with the following breakdown by source:

natural gas	8%
coal (synthetic gas)	16%
petroleum	76%

This quantity is projected to be at least twice as much as production of U.S. Frasch sulfur. Recovery of sulfur after combustion of fossil fuels is not included in the 11.7 million LT total.

Almost 7 million LT of S values are expected to be generated by U.S. smelters in the year 2000. About half of this total may be recovered in useful form.

For the continental U.S., the supply/demand balance might approximate (million LT in year 2000):

Supply		Demand	
Nat. & Syn. Gas	2.8	Domestic Demand	25.2
Petroleum	8.7	Net Exports	2.0
Smelting, etc.	3.2		
Frasch	5.0		27.2
	19.7		
Abatement S in Useful Form	7.5		
	27.2		

More than half of the abatement S in useful form may be recovered as acid. The Chicago region, i.e., the E.N. Central States, is expected to be the most important source of abatement sulfur.

7.5 Sulfur Demand

By the end of the century, the U.S. split between industrial and fertilizer demand is projected to be about 56% and 44%. On an absolute basis, U.S. fertilizer S demand is expected to be 11 million LT or 26% of world demand for fertilizer sulfur. For non-Communist countries, the approximate split between industrial and fertilizer demand for sulfur is expected to be (million LT):

	Industrial	Fertilizer
W. Europe	14.7	8.6
Japan	8.0	1.8
Canada	1.9	1.7
	24.6	12.1
Mid. E./Far E.	7.1	11.2
Lat. America	4.1	5.4
Africa	1.8	2.0
	13.0	18.6

Thus, in what are now considered to be the developed countries, the year 2000 split is expected to be 67% industrial and 33% fertilizer demand. The corresponding split in the developing countries is projected to be 41% and 59% respectively. When the projections for the two groups of countries are combined, the split becomes 55% industrial and 45% fertilizer, almost exactly matching that projected for the U.S.

7.6 Cost Projections

In spite of effective use of unit trains for transporting sulfur in both the U.S. and Canada, rail costs are projected to increase relatively faster than the costs of various kinds of water-borne transportation. This is seen as a disadvantage to:

(a) Landlocked locations (e.g., the Western states and Alberta).

(b) Mine-mouth power plants where abatement S may be recovered.

The transportation cost for acid, whether by rail or water, is expected to increase relative to the process cost of recovering S values as acid.

For the next 15 years, the F.O.B. price of sulfur recovered from Alberta sour gas is expected to be a major factor in establishing world prices for sulfur. It is judged that the Alberta price will not be less than $5/LT, is more likely to be about $10/LT and could be as high as $15/LT. Such prices are equivalent to F.O.B. prices for Frasch S on the U.S. Gulf of about $17/LT, $22/LT and $27/LT, respectively.

7.7 Computer Model

IBM's Mathematical Optimization Subroutine System (LP-MOSS) can be used to calculate the value of sulfur in different locations, given:

(a) Demand in each location.

(b) Availability of supplies and (assumed F.O.B. price at various locations.

(c) The cost of delivering sulfur from points of supply to points of demand.

The linear program calculates the solution giving the lowest overall cost to the purchasers. Such a "buyers' market" is consistent with projections of continuing oversupply or potential oversupply and also with the concept that the marketing advantages currently held by certain producers will be eroded with time. Thus, as long as "reasonably" free trade conditions apply to sulfur, customers may expect to obtain sulfur economically. "Reasonably" implies a middle course between (a) the hypothetical marketing conditions that could result from the dumping of gross oversupplies of sulfur at any price, and (b) resumption of high-cost Frasch production or return to high profit margins for Frasch production in general.

Different assumptions, falling within the "reasonable middle ground," may be investigated by computer calculations. After running a number of cases, it is possible to construct correlation charts which may then be used to investigate other "reasonable" assumptions without the need for additional computer runs.

Constraints can be built into the computer program to simulate factors such as the marketing strengths of certain producers or the shipment of sulfuric acid instead of elemental sulfur. However, no way has been found of calculating "value" under hypothetical conditions of gross oversupply and dumping. Judgment suggests a zero or negative value under such conditions.

When applied to historical data for the period 1960-1970, the computer program tracked price movements adequately. Nevertheless, the Model is not, and is not intended to be, a tool for predicting short range price movements.

7.8 Supply/Demand Balance and Constraints

- World oversupply is a virtual certainty for at least another 10-15 years, and is not likely to be corrected until after two related events have occurred:

  (a) Recovery of sulfur from W. Canadian sour gas has peaked--probably about 1980/81.

  (b) The stockpile of W. Canadian sulfur (which is expected to grow steadily for another decade) has peaked--probably about 1985/86.

- Subsequently, the actions taken with respect to abatement sulfur in the U.S. may determine which of the following comes to pass:

  (c) A re-emergence of sulfur shortage, leading to high cost production and/or substitution of manufacturing processes that do not require sulfur.

  (d) A reasonable balance, in which U.S. abatement S in useful form plays an essential part in domestic supplies and a significant part in recapturing export markets for sulfur.

  (e) Chaotic marketing conditions due to gross oversupply.

- Achievement of (d) would seem to require recognition that:

  (f) The demand for abatement S in useful form will be much less than the maximum quantity that (theoretically) could be produced.

  (g) For high levels of SO_x emission control, it will be necessary either to recover large quantities of abatement S in non-useful form or to recover elemental S and place it in national stockpiles.

  (h) Development of market outlets for abatement acid will be a slow process because changes in market structure are required.

  (i) Non-acid recovery systems will be essential for many installations during the next decade.

  (j) There may be no significant market outlet for abatement S recovered in places separated by high transportation costs from areas of net demand.

(k) The post-1980 increment in abatement S potential may be of the same magnitude as the post-1980 increment in demand for sulfur.

(l) The choice of recovery system during the period of retrofitting emission controls will be extremely important because the decision will have to be made:

- in the context of growing world oversupply even before inclusion of any significant increment of supply from treatment of stack gases.

- in recognition that rather small increments in supply could create a gross oversupply in individual markets.

(m) There are great differences among individual markets and that these markets are not fully connected from a supply standpoint, e.g., it would be quite possible for the U.S. as a whole to be in numerical balance while individual markets were seriously out of balance.

(n) The U.S. sulfur and sulfuric acid industries have well established structures.

(o) Purchase of elemental sulfur for manufacture and captive use of sulfuric acid is an extremely important feature of the current industry structure, particularly in the case of fertilizer acid.

(p) A new marketing structure may have to be evolved for abatement acid, and may well depend on the willingness of existing marketers to offtake such acid.

(q) Acid and elemental S have different values to different types of prospective customer, as well as different production (recovery) and transportations costs per ton of S equivalent.

(r) The best choice of abatement system for a given location will depend on the overall cost or credit to the operation. For planning purposes, this overall "profit" is [Maximum Delivered Value] minus [Transportation Cost plus Marketing Cost] minus [Recovery Process Cost].

(s) In many cases, the overall "profit" in (r) will be negative, i.e., abatement will involve a net cost.

(t) A throwaway system will always involve a net cost, but may be the optimum choice.

(u) If a net cost is indicated, the feasibility and cost of obtaining fuel of sufficiently low sulfur content (as not to require an abatement system) should be investigated. The possible need to abate emissions other than SO_x should be considered.

(v) Actions of other producers, who may not enter the market until (much) later, can affect the future "profit" obtainable by the original producer. Thus, when considering (r), (s), (t) and (u), it is also necessary to assess how the situation may change over a period of many years.

- In the distant future nuclear energy is expected, first, to be able to supply all of the incremental demand for energy and, subsequently, to make further inroads into markets supplied by fossil fuels. This may happen because of declining availability of certain types of fossil fuel or for economic reasons. It seems more likely that combinations of these reasons will apply, and that the pattern will not be uniform in different parts of the world or even in different parts of the U.S. However, once there is a decline in the consumption of fossil fuels, the world demand for sulfur may be expected progressively to overtake the potential supply of sulfur recoverable from fossil fuels.

- In aggregate, reserves of coal, oil shale, tar sands, and heavy crudes are very large. In the Model, it is assumed that these reserves will be a major source of U.S. energy supply during the next five decades. In consequence, a potential excess of sulfur is expected to extend through the year 2020. On the other hand, despite these fossil fuel reserves, it is conceivable that their economic competitiveness relative to nuclear energy may decline faster than has been anticipated in the Model. If this were to happen, both the world and the U.S. sulfur situations could swing to shortage sometime after the year 2000 but before the year 2020.

7.9 Future Value of Abatement Sulfur

Provided that gross oversupply is avoided, the delivered value of abatement S should be close to that obtainable for Frasch S in many parts of the U.S. (and for Alberta S in certain Midwest and Pacific N.W. locations). Geographical differences will reflect transportation costs and marketing factors such as captive terminals. In view of these differences, any single number may be misleading. However, on an order of magnitude basis, \$22-25/LT delivered would be representative of the current situation. By the year 2000, delivered values are expected to be about \$10/LT higher. The upturn is not expected to come until after 1985, i.e., not until after the W. Canadian stockpile has peaked. In fact, prices in the interim could go lower. This may be avoided if export prorationing by Canada, Mexico, France and Poland succeeds. If it does not, sulfur prices may bottom out around 1980 when W. Canadian production is expected to peak.

Abatement sulfur from U.S. sources will be superimposed on the pattern just described. The expected values depend on avoidance of oversupply of sulfur in useful form.

As an order of magnitude illustration, marketing and transportation costs of about $10/LT have been assumed for abatement S in elemental form. On this basis, the netback to the producer, before subtraction of process costs, might be about $12/LT in the early 1980's and about $22/LT a decade later. No generalization can be made for the value of abatement acid; it must be estimated for individual cases taking location and marketing factors into account.

8. POSSIBLE WAYS OF USING MODEL

8.1 Approaches Suggested for Use by E.P.A.

The model was developed specifically to help the Environmental Protection Agency to establish the relative merits of different research strategies. This section is confined to suggesting short-cut ways of doing this. The "long" ways are, of course, to run additional computer cases to investigate other assumptions or to expand the model as suggested in Section 6.3. Other possibilities are indicated in two subsequent subsections. Additional data may be needed for some of these potential applications.

8.1.1 Recovery Costs, Marketing Costs and Delivered Values

To investigate the optimum choice of abatement system, as suggested in Section 6.4, it is necessary to:

(a) Obtain the respective costs of recovering abatement S in different forms (or by different proprietary systems).

(b) Estimate the cost of marketing or otherwise disposing of recovered abatement sulfur.

(c) Subtract (a + b) from the estimates of maximum delivered value calculated by the computer runs.

It is believed that the Environmental Protection Agency already has estimates of the costs of different recovery processes. No doubt, these are on the basis of current expectations, i.e., applicable to systems that are already under development or have reached the demonstration stage. It is suggested that these estimates be supplemented with projections of what may be possible in the future. The estimated costs of second and third "generations" of abatement systems are needed for assessment of what choices may be available in the 1980's and later.

Estimation of marketing costs must be dealt with on a specific basis, even if the cases investigated are hypothetical. The regionalized demand forecast data indicate the volume potentials for abatement S. These potentials could be disaggregated into potentials for specific locations within a particular region. The capacity of existing sulfuric acid plants might be the basis for this disaggregation. Next, specific sources of abatement S should be located within the region. Different volumes and different forms of abatement S would be investigated in separate cases. The transportation cost data in Appendix 6 (using costs per ton-mile for a given year and transportation mode) would then be used to obtain the cost of moving all of the abatement S (assumed to be produced in each case) to the disaggregated points of demand (i.e., potential customers). The latter would be chosen to minimize the cost of disposing of the total quantity of abatement S assumed to be produced. Acid equivalency credits, as described in Appendix 6, could be applied in order to correct for the different value of sulfur in acid and elemental form. The sum of all of the costs and credits ("negative costs") would then be deducted from the "maximum delivered value" already estimated by the computer calculations. The result would give an indication of whether recovery of acid would be preferable to elemental S. The result could be either a net cost or a positive netback. If the latter, it would be prefereable to a throwaway by-product. If the former, it would be necessary to compare the net cost with that of making and disposing of a throwaway by-product.

The foregoing involves a number of simple steps that lead to a preliminary indication of "best choice." However, three other questions remained to be answered:

(a) How would the marketing be accomplished? (Clearly, this cannot be calculated.)

(b) How would the choice be affected by other (additional) quantities of abatement S in the same region?

(c) Would it be feasible to obtain fuel of sufficiently low S content to avoid the need for an abatement system, and what would this approach cost? (Taking into consideration that abatement of more than SO_x may be required).

The marketing question might be left unanswered (i.e., by making the tacit assumption that a way will be found) or by making contacts with acid marketers as suggested in Part 2 of the report. A suggested way of dealing with (b) is explained below. A separate study would be needed for (c).

8.1.2 Establishment of Regional Market Potentials

The charts correlating net regional demand with the quantity of abatement S that may be marketable also indicate the maximum delivered value for abatement S corresponding to a given quantity of the latter in useful form.

The parametric demand cases have the effect of increasing the quantity of abatement S that could be absorbed by the market without depressing the delivered value. Transfer of abatement S to a national stockpile (analogous to a stockpile of a surplus agricultural commodity) would have a similar effect on a current basis. It would have the additional effect of making the stockpiled sulfur potentially available in subsequent years. This will be discussed in the subsection that follows. For the moment, the potentialities of a national stockpile will be disregarded.

At this point, it is assumed that the E.P.A. will be interested in investigating cases in which abatement S has a value rather than hypothetical cases representing gross oversupply with consequent zero or negative value. As discussed here, "gross oversupply" occurs when abatement S in useful form is assumed to be produced in excess of net regional demand and there is no obvious extra-regional outlet for the excess. The point of gross oversupply for each region is apparent from the pertinent correlation chart. What has not been established is the point of "incipient oversupply." Conceptually, this would occur before the regional supply of abatement S in useful form exceeded the net regional demand. Arbitrarily, it might be assumed that this would occur when about 90% of net regional demand was filled with abatement S (but E.P.A. may prefer either to assume a different % or to investigate the effect of several different percentages).

The point of incipient oversupply establishes the quantity of abatement S in useful form that is conceived to be marketable at prices capable of giving a positive netback to regional suppliers. In consequence, this is the quantity that may be divided up among individual recoverers of abatement S within the region. This, then, is the suggested answer to (b) in the previous subsection.....any number of regional abatement sources may be located within a given region provided that the total of their assumed production of sulfur in useful form does not exceed the quantity representing the point of incipient oversupply.

8.1.3 National Stockpiles

The establishment of national stockpiles of elemental S derived from abatement sources would be a matter of national policy. Clearly, it would provide incentives for recovery in elemental form. However, it could also provide benefits to recoverers of abatement acid since a certain quantity of elemental S would be removed from the market. It might also be a mid-term alternative to throwaway systems.

It is suggested that the E.P.A. defer detailed investigation of the stockpile question until headway has been made with the suggestions given in Sections 8.1.1 and 8.1.2 because the latter would provide the "base cases." If it is accepted that world oversupply will continue until late in the 1980's, then it follows that the prospects for exporting abatement S* will not be favorable until the late 1980's. From an export standpoint, elemental S will be required, but this need may not develop for almost two decades. In this context, there is no immediate need for research that would lead to recovery of elemental S, if, at the same time, the only outlet for the recovered S were to be in stockpiles.

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* or for permitting other U.S. production of S to be exported.

8.2.3 Deviations from Free Trade

As discussed in Section 6.6, it would be possible to examine a spectrum of different assumptions involving departures from free trade. This would involve the placing of constraints on the U.S./foreign linkages in the "North American Model". Both imports and exports would be affected by such constraints. While recognizing the key role that sulfur plays in industry and agriculture, it must be pointed out that international trade in sulfur represents a minute percentage of the total value of all international trade. Thus, restrictions on sulfur imports or exports would have a small impact on the Balance of Trade (or B.O.P.) of most countries. However, local effects could be significant, e.g., to the Province of Alberta or state of Louisiana (or counties of Jefferson or Plaquemines). Considerations of this kind were brought out in testimony by the U.S. sulfur industry to the U.S. Tariff Commission during the period November 1970 to March 1971. A listing of this testimony is given in Table 8.

8.2.4 Future Domestic Possibilities

The concepts of what is fair and reasonable in foreign trade may set precedents for the future of the domestic sulfur and sulfuric acid industries.

In the long term, the business of the U.S. Frasch sulfur producers, who have reserves for another 40 years or, perhaps, longer, is threatened not by sulfur recovered from Canadian sour gas but by S values recovered from fossil fuels in the U.S. itself.

Just as there is a demand for Canadian gas, there will be a continuing demand for fossil fuels in the U.S. Increasing quantities of sulfur will be recovered in elemental form before the fuels are burned. In addition, S values will be recovered from stack gas and smelters. If acid is produced, it will reduce the demand for elemental S that would otherwise be used to manufacture acid. If elemental S is recovered, it will compete directly with U.S. Frasch sulfur.

Fortunately for the Frasch producers, the principal areas of S demand are in Florida and on the Gulf Coast. These markets are reasonably, but not completely, insulated from abatement sulfur. But the markets are not insulated if abatement sulfur were to be moved at any cost. Quoting from Freeport's testimony (Item 2 in Table 8):

> "They have stockpiled some of their excess production and they could easily stockpile more. Instead, they have elected to follow a policy of persistently cutting prices in an effort to force their sulfur into markets already fully supplied."

and:

> "Unless some way is found to enable the U.S. sulfur industry to market its sulfur on a fair and equitable footing with this by-product competition, the industry faces continued shutdown of mines, cutbacks of production and reduction of employment."

The previously suggested tasks would establish the relative values of different forms of abatement S in terms of the quantities expected to be marketable in different regions. This would be done without consideration of stockpiling, i.e., the implicit assumption is that abatement S would not be recovered in useful form unless it was estimated that it could be marketed at the rate at which it was produced. If recovery in elemental form is favored under these conditions, e.g., for the years 1980 and 1985, then the desirability of speeding the development of effective and economical systems for recovering elemental S would be obvious--without the need for any justification relating to national stockpiles. However, recovery in elemental form may not be favored. This could be because the recovery cost is projected to be relatively much higher than that of acid or of a throwaway by-product. On the other hand, difficulties with the safe disposal of throwaway products are conceivable. Such a situation would seem to make it essential to develop elemental S recovery systems as soon as possible--with the definite expectation that much of the sulfur so produced would have to be stockpiled for many years.

Thus, there would seem to be at least two substantially different purposes for national stockpiles:

(a) To provide a springboard for eventual exports of abatement S.

(b) To overcome a (hypothetical) difficulty with throwaway by-products by development of a "storeaway" alternative.

Although (a) is not incompatible with (b), it would seem preferable to obtain a preliminary assessment of the merit of each. In this way, investigation of stockpile cases (extensions of 8.1.1 and 8.1.2) could be undertaken in the light of the purpose that the stockpile was expected to accomplish. It is believed that the purpose could have a bearing on the total quantity of abatement S that might reasonably be stockpiled and, thus, on the quantitative assumptions that should be investigated.

Two further possible uses for national stockpiles may be mentioned. The first depends on the reasoning given in the final paragraph of Section 7.8, namely that nuclear energy is expected, eventually, to cause a decline in the potential for recovering sulfur from fossil fuels. In this context, sulfur stockpiled during the next several decades would be conserved for future use, even though such use might be long delayed.

The second possibility is entirely different. Here, it is conceived that stockpiles of elemental S might be used to give flexibility to an overall abatement program. The latter might be designed to balance the production of abatement S in useful form with market requirements. However, demand cannot be predicted exactly, and certainly not for the entire life of an "abatement plant". In this case, temporary surpluses of abatement S might be taken off the market and placed in national stockpiles. At the same time, policy with respect to new abatement plants might be varied (through revision of projected future markets for abatement S in useful form) in order to keep the stockpiles at a low average level. Used in this way, the stockpiles would be a means of partially protecting individual abatement plants from errors in the estimation of future supply/demand balances for sulfur. With the further assumption that accelerated depreciation may be permitted for abatement systems, stockpile "protection" might be given during the period when the capital cost of the abatement plant was being amortized.

The third and fourth stockpiling possibilities appear to be matters of policy that cannot be investigated by use of the Model. On the other hand, the establishment of policy with respect to such possibilities could be helpful to the investigation of (a) and (b).

8.2 Investigation of Alternative Assumptions

Section 6 discussed the sensitivity of the assumptions that provided the basis for computer inputs etc. Some of these sensitivities could be investigated through the simple expedient of making other assumptions, while others would require additional information.

8.2.1 Economic Development

The effects of different rates of economic growth could be investigated by following the procedures outlined in Appendices 1-5. Such variations would be translated into differences in sulfur supply and demand. Approximate values could be obtained, without detailed calculations, by proration (i.e., direct correlation) of sulfur supply and demand with constant dollar GNP (e.g., 90% of GNP relative to Model's GNP projection would imply 90% of Model's projections of pertinent supply and demand). If significant differences were indicated by this short-cut approach, detailed calculations might be undertaken.

8.2.2 F.O.B. Prices and Transportation Costs

Cost assumptions may be varied once the low cost supplier (who has incremental supplies) in a given market is known. This supplier is the price-setter. If it is assumed, arbitrarily, that he would lower his price by $X/LT, then other suppliers would be forced to do the same. Investigation of higher price assumptions is somewhat more complicated in that another supplier may become the price setter for an increase of less than $ X/LT. Thus, a new LP case might have to be run. However, the general effect of a hypothetical price increase (by an individual supplier of a given market) above the delivered price capability of the next incremental supplier would be "no sales" in that market. While the foregoing applies to assumptions concerning "minimum F.O.B. prices", exactly the same approach could be used to investigate different transportation cost assumptions.

8.2.3 Deviations from Free Trade

As discussed in Section 6.6, it would be possible to examine a spectrum of different assumptions involving departures from free trade. This would involve the placing of constraints on the U.S./foreign linkages in the "North American Model". Both imports and exports would be affected by such constraints. While recognizing the key role that sulfur plays in industry and agriculture, it must be pointed out that international trade in sulfur represents a minute percentage of the total value of all international trade. Thus, restrictions on sulfur imports or exports would have a small impact on the Balance of Trade (or B.O.P.) of most countries. However, local effects could be significant, e.g., to the Province of Alberta or state of Louisiana (or counties of Jefferson or Plaquemines). Considerations of this kind were brought out in testimony by the U.S. sulfur industry to the U.S. Tariff Commission during the period November 1970 to March 1971. A listing of this testimony is given in Table 8.

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and:

> "Unless some way is found to enable the U.S. sulfur industry to market its sulfur on a fair and equitable footing with this by-product competition, the industry faces continued shutdown of mines, cutbacks of production and reduction of employment."

These remarks were aimed at Canadian recovered sulfur. However, they might well become applicable to U.S. abatement sulfur. The parametric cases of the Sulfur Model reveal the conditions under which this could occur. These cases are hypothetical. Abatement sulfur, surplus to regional needs, may be produced in throwaway form or may be stored in stockpiles until needed. The Model considers the arithmetic of these possibilities, but it is not able to deal with the economic and political implications of gross oversupply and (hypothetical) sale of recovered sulfur down to, or even below, zero netback. Others may wish to use statistics developed for the Model as a starting point for investigating the consequences of different abatement sulfur policies.

8.2.5 Revision of Model to Accord With Energy Policy

How much fossil fuel energy is consumed, the proportions of each fuel type, and the split between domestic production and imports will all affect the abatement sulfur potential. However, the fossil fuel questions themselves will be worked out in the context of national energy policies.

As suggested in Section 6.7, once a national energy policy is established, it would be possible to investigate its impact on the sulfur industry by use of the Model. Alternatively, a broad range of possible policies could be postulated, and the expected effects of these policies could be simulated by the Model.

TABLE 8

TESTIMONY ON THE SULFUR INDUSTRY SUBMITTED TO THE U.S. TARIFF COMMISSION

1. Statement, dated 11/13/70, on behalf of the Duval Corporation (a subsidiary of Pennzoil United)--15 pages.

2. Testimony of the Freeport Sulphur Company, dated 11/13/70--9 pages.

3. "Alternative Approaches to Determining the Production Costs of Sulfur from Sour Gas Fields in Western Canada," report dated 12/1/70, by A. D. Little Inc. to the Duval Corporation--59 pages.

4. Opinion of Arthur Anderson and Company concerning accounting principles applicable to by-products and co-products, dated 12/1/70--3 pages.

5. Statement of Freeport Sulphur Company dated 12/1/70--34 pages.

6. "The Sulphur Crisis: Causes and Remedies," statement by the Duval Corporation dated 3/15/71--37 pages.

7. Supplemental statement of Freeport Sulphur Company dated 3/30/71--8 pages.

8.3 Other Applications

8.3.1 Comparison with Specialized Forecasts

The appendices contain information that could provide input or departure points for other studies. Economic development, energy demand, fossil fuel availability, fertilizers, sulfuric acid, phosphoric acid are all possibilities.

It may seem presumptuous to make this suggestion since each one of these subjects will have been studied in great detail by others. However, the particular advantage of the Model is that all of its components have a common and compatible basis. In general, this would not be true of specialized forecasts for a given business sector and, perhaps, confined to the U.S. Such forecasts may be highly sophisticated, e.g., in their assessment of future technological developments, yet also naive in treating business developments as if they could occur in isolation from the rest of the U.S. or world economy. Thus, it may be of interest to compare the results of specialized forecasts with those in the Model. Differences are probable, partly because of the crudities in the Model but also because a given specialized forecast may have been made without sufficient attention to its fit with external and international factors. Uncovering the reasons for the differences could lead to improvements in the Model and the specialized forecast.

8.3.2 Development of Natural Resources

The Sulfur Model would not be directly applicable to this suggestion. The work done merely indicates that such a study might be desirable.

Many foreign centers of population and industry are within cheaper access of corresponding U.S. centers than are landlocked locations in the U.S. This problem will be of critical importance to the development of natural resources in the Western states. Coal, phosphate rock, minerals recoverable from the Great Salt Lake, shale, dawsonite, trona etc. are in locations distant from points of major demand. However, the problem is transportation cost rather than distance per se. Looked at this way, in relation to commodities of low unit value, Chicago may be "closer" to Rotterdam than Tucson is to Los Angeles. And Los Angeles is "closer" to Nagoya than to Detroit.

The escalation of rail transportation relative to water borne transportation costs has been discussed in Section 6.5 and in Appendix 6. Water availability has always affected the location of industry and distribution of population. In the future, the dependence may be even greater and may extend to the need for navigable water in addition to that needed for general industrial or agricultural purposes.*

Pipelines offer a solution to the transportation cost problem in some cases but not in others. Long distance pipelining of low BTU synthetic gas from coal may not be economically feasible, while the technology for moving solids by pipeline is still relatively new. Furthermore, efficient use of pipelines requires continuous use at almost constant, and high, throughput. Anhydrous ammonia and fertilizer solutions can move efficiently by pipeline but, in general, agricultural produce cannot.

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* "The Nation's Water Resources", U.S. Water Resources Council, Washington, D.C., 1968 provides much information on these subjects including projections of resource needs until the year 2020.

The foregoing observations lead to the suggestion that the further development of natural resources may be studied in terms of transportation costs between points of occurrence and points of demand. The individual resources will have different transportation costs that, in some cases, will depend on their form (e.g., whether coal is transported as such, or as a slurry, or as a gas, or as electricity). Hence, a computer model could be constructed that would permit calculation of the lowest cost total system of resource utilization. The theoretical lowest cost "solution" might have unacceptable implications (e.g., impact on exisiting industries and employment patterns). However, a computer model should make it feasible to investigate many different cases. The implications of these cases could provide insight into the long range consequences of different policies for the development of Western or other natural resources.

8.3.3 Business Applications of Sulfur Model

The Model is based on the assumption that all sulfur from a particular point is supplied at the same F.O.B. price, regardless of destination. In reality, however, Canadian, U.S. and Mexican producers have operated what is usually referred to as a "dual price" system, but what is actually a multi-price system. Thus, the true netback of sulfur sold in Alberta has been different from the netback for a shipment to the U.S. and different again from the netback for an "offshore" sale. In the case of the U.S. Frasch producers, different netbacks are being obtained for deliveries to Tampa, Chicago, and N. Europe. These differences have a relatively minor effect on the values calculated for abatement sulfur, but would be extremely important to sulfur producers. The Model could be adapted to simulate multiple pricing and to the planning of marketing strategies to obtain maximum profitability under conditions of general oversupply.

9. GLOSSARY

The precise implications of more than forty terms must be known in order to remove possible ambiguity from the language of the report. Many of the terms are in current use, but may have different implications when used by different authors. Other terms have been coined for specific application to the Model. In one case, "abatement sulfur," the definition for the purpose of the Model is much narrower than conventional usage. This Section is confined to definition of such terms. The reasoning behind the choice of terminology will be found in other Sections of the report. Certain terms that are specific to computer terminology are explained in Appendix 7 and are not repeated here.

The glossary follows what is believed to be a logical sequence of concepts, rather than being arranged alphabetically.

- Deliberately produced sulfur is also referred to as discretionary sulfur. It implies production where the sole, or principal, purpose is to produce sulfur for sale. Frasch S is the most obvious example. Production of acid from pyrite, particularly outside the U.S., is usually in this category also.

- Co-product sulfur is also produced deliberately. In this case, however, the other co-product (frequently "metal values" from which copper and other non-ferrous metals are recovered) may be of equal importance. For this reason, the economics of producing co-product S differ from those where sulfur is the sole product.

- By-product sulfur is associated with producing something else as the main product. In most cases, the by-product sulfur is produced in the course of making another product marketable or more readily marketable. Examples are by-product S from sour natural gas or from desulfurization of petroleum. An unequivocal distinction between co-product and by-product sulfur is not possible because the situation may vary geographically or with time. The practical distinction is that co-product S must bear a share of production costs while, in the limit, the principal product may have to bear all the cost of producing by-product S.

- Recovered sulfur is a broad term covering sulfur produced by any process except mining. Recovered S values refer to sulfur in any form and produced in any way except by mining.

- Abatement sulfur, for the purposes of the Model, refers to S values (in useful or throwaway form) recovered by electric utilities. The term also includes the special case of S values recovered in excess of local needs from smelters in the Mountain states ("Tucson region" of the Model).

- *Abatement potential* is the total quantity of abatement S that could, theoretically, be recovered. It does *not* imply the market potential for abatement S.

- *Abatement sulfur in useful form*, for the purposes of the Model, is limited to abatement S recovered as sulfuric acid or in elemental form. "*Waste gypsum*," "*throwaway form*," and "*non-useful form*" are synonymous in the Model (even though the possibility of utilizing waste gypsum is recognized).

- *Overhang* or *abatement overhang* refer to the quantity of abatement S that could be recovered as the consequence of *retrofitting* systems for recovering abatement S in order to comply with SO_x emission standards.

- *Abatement level* implies the degree of control of SO_x emissions achieved at a given time. In general, the abatement level is considered in relation to the total quantity of SO_x emitted in 1970. In most cases, the abatement level is measured in terms of million long tons of *sulfur equivalent* rather than in terms of sulfur oxides.

- *Increment over 1970 (abatement) level* implies the quantity of S equivalent contained in abatable emissions above the 1970 level of such emissions.

- *Percentage reductions from 1970 level of SO_x emitted* refer to the *percentage* abatement from the 1970 level. Such reductions may also be expressed in terms of million long tons of S equivalent, but do not necessarily imply that such sulfur would be in useful form. The quantity of sulfur abated multiplied by the percentage of such recovery in useful form is the quantity of abatement S in useful form.

- *Gross regional demand* refers to the total sulfur demand of a given region of the Model, before taking account of any supplies of sulfur from within the region.

- "*Netting out*" refers to subtraction of regional supplies from gross regional demand in order to obtain *net regional demand*.

- The *base case of net regional demand* excludes regional supplies of abatement sulfur in useful form. *Parametric cases of supply of abatement S in useful form* lead to cases of net regional demand that do take account of regional abatement supplies in useful form. Such parametric supply cases simulate "*exogenous supplies*."

- *Parametric demand cases* involve assumptions that gross regional demand is increased by certain percentages. Such cases simulate "*exogenous demand*." When permuted with the parametric supply cases, a series of parametric cases of net regional demand is obtained.

- National stockpiles of elemental sulfur, as treated in the Model, are conceived to remove abatement S in elemental form from the market until needed. From the standpoint of computer calculations, the immediate effect of a national stockpile is mathematically equivalent to a reduction in the supply of abatement S in useful form and, thus, is called "negative supply."

- Extra-regional suppliers refer to regions projected to have both an excess of supply over regional demand for sulfur and also the capability of delivering such supplies to one or more regions of net demand. Certain regions that start out in a net demand position are projected to become extra-regional suppliers in later years.

- Gross oversupply may be regional, multiregional, or general (i.e., essentially worldwide). On a regional basis, gross oversupply is considered to occur when (a) regional supplies of sulfur exceed regional demand, and also (b) no outlet for the regional surplus can be envisaged outside the region, or (c) extra-regional markets are insufficient to accommodate the surplus. For the purposes of calculation, gross oversupply has been considered on an annual basis and as if there were complete flexibility in offsetting intra-regional demand with intra-regional supplies. These assumptions are recognized to be inadequate, and lead to the concept of incipient oversupply. This is the condition under which individual regional producers of sulfur are postulated both to anticipate the onset of oversupply and also to attempt to market their own production before their competitors saturate the available market. Rapid erosion of delivered prices is assumed to begin beyond the point of incipient oversupply. Arbitrarily, this point is assumed to occur when, under conditions of (a) plus (b) above, 90% of regional demand is satisfied by regional supplies. However, this 90% concept does not apply to condition (c) i.e., when the given region becomes an extra-regional supplier. In this case, no percentage can be postulated because the regional balance will depend on the extent of extra-regional markets while taking account of the potential action of other extra-regional suppliers in the same extra-regional markets.

- Indeterminately low value for abatement S in useful form refers to value under conditions of gross oversupply.

- Sulfur may or may not be offered for sale on the basis of free-on-board (F.O.B.) or free-on-rail (F.O.R.) prices. In concept, such prices, after the addition of the total costs of delivery (i.e., transportation plus marketing costs), are equal to delivered prices.

- Prices, costs, and values have different meanings. The computer program uses (assumed) F.O.B. prices and delivery costs in order to calculate maximum delivered values (M.D.V.) for sulfur in the various regions. The M.D.V. for abatement sulfur in useful form is equal to the delivered price of deliberately produced sulfur (usually from an extra-regional source) in a given region, up to the point of regional oversupply. Beyond this point, M.D.V. is assumed to decline rapidly as regional supplies increase (i.e., the delivered price of extra-regional supplies is no longer assumed to "support" sulfur prices within the region).

- The term free-on-board value (F.O.B.V.) is used in relation to abatement sulfur in useful form. It is equal to the calculated M.D.V. minus total delivery costs (i.e., transportation plus marketing costs) from the plant where abatement sulfur is recovered to the points to which it is delivered. In cases where abatement S in useful form is assumed to enter extra-regional markets, F.O.B.V. is a value calculated by the computer program in the same way that the netback to other extra-regional suppliers is calculated. Where no extra-regional outlets for abatement S are assumed, rough estimates of F.O.B.V. have been provided by deducting $10/LT from the M.D.V. calculated for the particular region. This deduction has been made solely for the purpose of giving the reader an order of magnitude impression of what the regional F.O.B.V. might be. Specific information on location, marketing costs, etc., is needed in order to calculate F.O.B.V. from M.D.V.

- Abatement acid, for the purposes of computer calculations, is assumed to be 100% sulfuric acid of conventional commercial quality. Deviations from this quality should be considered when assessing the value of abatement acid that may be produced in a given location. The calculations treat abatement acid in terms of millions of long tons of sulfur equivalent in the form of 100% sulfuric acid.

- Acid equivalency credit is a device for taking account of the fact that the receipt of S equivalent in the form of acid may be more valuable than in elemental form. In the computer program, the credit is subtracted from the delivered price of sulfuric acid to permit rational competition between acid and elemental S in the LP calculations. The credit and other factors concerning acid are expressed as $ per LT of S equivalent.

- References will be found to "marketing strengths" and similar qualities attributed to existing production/marketers of elemental suflur and manufacturer/marketers of sulfuric acid. These "qualities" refer to physical facilites (such as liquid sulfur terminals and tankers) and also to the intangible advantages of business experience.

- Captive uses may be considered as a special aspect of "marketing strengths." Various structures of captive consumption are possible. The most notable are (a) forward integration by producers of Frasch S into the manufacture of phosphate fertilizers, and (b) purchase of elemental S for manufacture and captive use of sulfuric acid.

- Merchant acid sales may be integrated with captive utilization of sulfuric acid.

- Free trade is used in its international sense (and has no relation to U.S. "fair trade" concepts). It must be recognized, however, that free trade is an ideal rather than a reality. Hence, the Model deals with "relatively free" trade and takes account of the more significant deviations that concern sulfur.

- Production prorationing refers to compliance with production quotas set by (foreign) government authority (in the interest of maintaining what may be judged to be reasonable price levels by the avoidance of oversupplies). In some cases, minimum F.O.B. prices may be established directly, instead of through the indirect mechanism of production prorationing. In the case of by-product sulfur, where production cannot be controlled, a similar result may be achieved by export prorationing. This form of prorationing is equivalent to compulsory stockpiling.

- Dual pricing in its most common form refers to a different F.O.B. price base being used for domestic and export sales. The F.O.B. price base may be explicit or implicit (i.e., calculable by deduction of estimated delivery costs from delivered prices).

PART 2

FACTORS AFFECTING THE RELATIVE VALUE OF SULFURIC ACID AND ELEMENTAL SULFUR

1. Preliminary Remarks

It would be convenient to be able to give concise, all inclusive answers to questions about the absolute, or relative, values of sulfuric acid and elemental sulfur. However, such values will depend on a variety of factors and circumstances:

- geographical--location of sulfur source (e.g. S recovery plant) in relation to prospective markets.
- time--next year?, 1980?, 2000?
- Who is recovering what?--the business characteristics of the S producer, and whether elemental sulfur or acid is produced, may affect the ease with which marketing of S values can be accomplished--a given company may produce in different locations; this would affect overall marketing strategy as well as the value of incremental production.
- Who will market the product?--direct marketing may be involved, perhaps as an addition to existing business--or a long term offtake contract may be signed--What type of customers are in prospect?--are captive operations involved?
- How much is to be produced?--perhaps it will be a small quantity in relation to local demand--perhaps it will exceed what local markets could absorb, even if current suppliers were to withdraw.
- What storage and transportation facilities will be needed?--There may be interactions with how much and what is being produced.
- What is the overall context and what repercussions are possible?--a new supplier may have a minimal or an important impact on the existing market structure--in the latter case repercussions must be expected--also, other new suppliers will enter later and may change market structure or price levels even if the subsequent entry points are geographically distant from the new sulfur source presently under consideration.

Neglect of any one of the above factors could make our new supplier come to wish that he had made a different choice.

Generalizations about recovered sulfur values may be needed to illustrate the broad perspectives of future possibilities, but they are not a basis for planning. In particular, they are not a basis for planning the recovery of abatement S as sulfuric acid. As a generalization, there will be a need for effective acid recovery systems. However, installation of any such capacity in certain locations or of more than certain capacities in any location could lead to a *negative* value for acid produced. The reasoning behind these statements is explained in the report sections that follow.

Location is of paramount importance in the sulfur industry. An example will dramatize the point. It happens that the reserves of natural gas in Alberta and in Louisiana are of the same order of magnitude. However, on average, the former are very sour while the latter are sweet. If the reverse were the case, most of the U. S. Frasch mines might be shut down, and the remainder would be facing closure as production of by-product sulfur from sour gas grew steadily next door to prime markets for sulfur. In practice, however, the isolated location of the Alberta sour gas fields and, hence, the transportation costs to areas of significant demand afford a measure of protection to the U. S. Frasch S producers. If location is important in the case of elemental sulfur, it is even more important in the case of sulfuric acid, because acid costs more than three times as much to transport per ton of sulfur value.

2. Summary

U. S. consumption of sulfur is mostly in the form of acid. Thus, recovered sulfur has a different value depending on whether it is recovered as acid or as elemental sulfur. Theoretically, acid has the higher value because it means that the customer does not have to bear the cost of manufacturing it. However, the cost of transporting acid is at least three times greater than for elemental S per ton of S-value. In consequence, the greater value of recovering acid rather than elemental sulfur is critically dependent on *assured*, *local* markets for *all* of the acid produced. Unless these conditions are fulfilled, the value of acid may be low and it may even be negative. Elemental sulfur can be stockpiled; in most cases at small cost. Sulfuric acid can not be stockpiled.

At the end of 1965, just over half of U. S. sulfuric acid capacity was in 6 states: Florida, Texas, New Jersey, Illinois, California and Louisiana. Today, the industry is even more concentrated on the Gulf Coast and in Florida, with a relative loss of capacity in the Midwest. The geographical trends reflect the importance of Florida's pebble phosphate deposits and the development of chemical industry on the Gulf Coast.

Most of the acid used to manufacture P fertilizers is produced captively. This is true of a significant percentage of industrial acid as well. Some of the acid manufacturers also have captive production of S values. This applies not only to the special case of acid recovered by smelters but also to combinations of:

- Frasch S production and P fertilizer manufacture.
- S recovery from oil-and-gas operations and P fertilizer manufacture.
- S recovery by chemical companies and manufacture of industrial acid.

The structures and geography of the elemental sulfur and acid industries will make it difficult for abatement acid to enter the market. The willingness of existing acid marketers and captive users to offtake abatement acid is necessary if a significant outlet is to be developed. The incentives for such offtake have not been established yet. Currently the acid manufacturers, particularly those who merchant industrial acid, stand to benefit if abatement S were to enter the market in elemental form but to lose if entry were to be as acid. On the other hand, a significant amount of old acid plant capacity will soon need replacement. The shutdown of such capacity may provide the opportunity for some abatement acid to enter the market.

The total potential for abatement acid systems until 1980 may be equivalent to the acid recoverable from twenty 800 MW power stations operating at 60% load factor on 3 wt.% S coal. Thus, development of outlet for acid recoverable from power plant SO_x is expected to be slow. It follows that alternatives to acid recovery will be essential for the near term.

Details of the age, capacity, location and ownership of U. S. acid plants have been tabulated and analyzed.

A mathematical treatment of the relative economics of recovering abatement S in the form of (a) sulfuric acid, (b) elemental sulfur, and (c) as a throwaway product is given in Section (13).

3. Overall Conclusions and Supporting Reasoning

The development of outlet for acid recoverable from power plant SO_x will be a slow process and, for this reason, non-acid recovery systems will be essential for many installations for the near term.

The willingness of existing acid marketers and users to offtake abatement acid is necessary if a significant outlet is to be developed. However, this will require the offtakers to make radical changes in their business operations. The changes will involve difficulty and risk, and will not be undertaken without adequate incentives.

Currently, the incentives for offtaking abatement acid are not clearly defined. In fact, the abatement acid potential may be regarded more as a threat than as an opportunity. The potential threats are erosion of acid prices, loss of market position by individual acid merchanters, and premature obsolesence of existing investments in manufacturing plants and other facilities. Nevertheless, many existing acid plants are old, and some will be shut down by 1975 because economic compliance with pollution control regulations will not be possible. The latter will supply an incentive for arranging to offtake abatement acid instead of building a new captive acid plant.

It must be considered that many acid manufacturers are benefitting from today's low prices for elemental sulfur. If recovery of abatement sulfur were to be in elemental form, such manufacturers would continue to enjoy this advantage. In fact, the delivered price of sulfur might well drop further in some locations. In contrast, if recovery occurs in acid form, this will tend to put pressure on acid prices in local markets.

Matching the size of an abatement acid plant to the outlet available to an existing acid marketer or consumer may be difficult even if the latter shuts down an existing plant. A single 800 megawatt plant, burning 3 wt. % S coal and operating at an average 60% load factor, could produce about 140,000 ST/yr. of 100% acid.

Considering the states in which coal accounts for a significant percentage of electricity generation, there are only three; Florida, New Jersey, and Delaware, in which the electric utility abatement acid potential does not exceed conceivable acid outlet several fold (assuming an abatement acid price low enough to induce existing manufacturers to shut down their own acid plants). Eventually, this situation may change. Indeed, this is expected in the 1980's. However, it seems certain that only a fraction of the abatement sulfur that is recovered during the next decade can be in the form of acid. The limitation is one of market outlet within a given industry structure. The structure will change, but this will require time.

An important implication of the above reasoning and conclusions is that, near term, it will be essential for many power stations to recover or remove sulfur in forms other than acid. The market for SO_2 is small, and that for ammonium sulfate is declining. Hence, apart from using low sulfur fuels (if available), the only broadly applicable choices appear to be elemental sulfur and waste gypsum. This is not to say that acid recovery systems will not be useful, but it does say that the larger part of the problem will require another solution.

4. Industry Structure

The industry has several, almost separate elements. The most significant points are that (a) most of the demand for sulfur is in the form of sulfuric acid, (b) most of the basic supply is in the form of elemental sulfur, and (c) the sulfur producers and the acid manufacturers, for the most part, are different companies. These facts are highly pertinent to the value that can be ascribed to recovered sulfur, because the latter will have one value in elemental form and another value as acid, and these values will vary with location such that acid may be the more valuable product in one place while elemental sulfur may be more valuable in another.

Table 1 is a fairly complete listing of the companies participating in the U. S. sulfur/sulfuric acid business. A rough classification by type of company* reveals:

- 3 Frasch producers (Duval, Freeport, TGS)
- 10 oil companies (including agricultural affiliates such as Continental's Agrico and Union's Collier Carbon)
- 3 major acid companies (Allied, Olin, Stauffer)
- 12 major chemical companies (Dow, DuPont, Monsanto, etc.)
- 6 "special situation" or recovered acid companies (e.g. N.J. Zinc, U.S. Steel, etc.)
- 7 agricultural and agricultural specialty companies (including Grace and Columbia Nitrogen)
- 15 small specialty chemical companies
- 12 resellers

It is apparent that very few companies are both producers of sulfur and marketers of acid. This means that most of the acid is manufactured either from purchased sulfur or is the by-product of smelting, etc. Some of the companies that make by-product acid are direct marketers of acid, while others (not listed in Table 1) sell spent acid or H_2S to companies such as Stauffer and Allied Chemical.

Future producers of by-product acid may wish to avoid becoming direct marketers, i.e. merchanters of sulfuric acid. Such companies may try to arrange for their production to be taken off their hands by existing marketers. The acid from several such operations might be removed to a central point in a given marketing region. The central point would have blending facilities to permit the marketing of various grades of acid, oleum, SO_2, etc. It is anticipated that the transfer price for such recovered acid, F.O.B. plant, may be much lower than the normal market price for sulfuric acid. Conceptually, a significant differential will be required to compensate a reseller/marketer for his collection/blending/marketing operations and for providing security of supply to customers (not possible from a single by-product acid source).

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*The classification is not intended as a complete characterization of the named companies' business.

Within the next decade or two, the U.S. industry and its Canadian affiliates may be classifiable as follows:

(1) Frasch producers-- marketers of elemental S via liquid terminals in Gulf Coast, W. Florida, Mississippi river system, and E. Coast--having substantial forward integration into manufacture of P fertilizers.

(2) Some oil companies with integrated elemental sulfur/acid operations and, in some cases, P fertilizer manufacture.

(3) Nationwide sulfuric acid companies -- major purchasers of U.S. Frasch and imported (mainly Canadian) sulfur -- major purchasers/resellers of recovered acid, and contract operators of recovered acid plants for electric utilities.

(4) Chemical companies with capability for merchanting some of own acid production--purchasers of elemental S from Frasch producers and Canadian/Mexican suppliers -- Eventually the increasing supply of recovered acid obtainable by special arrangement or from nationwide acid suppliers may induce these chemical companies to shut down their own acid plants (i.e. not add new capacity when existing plants are worn out).

(5) "Special situation" producers of recovered acid in individual locations (not nationwide marketers) primarily NFM smelters who elect to market their by-product acid rather than sell it under contract to nationwide acid companies.

(6) Specialty marketers and chemical companies, mostly small in size, and mostly operating only on a local (not a national) basis--who will obtain their raw materials from a variety of sources.

(7) Small-scale resellers of acid, etc.---some companies of this type will come into being in response to the opportunities created by availability of recovered S-values in locations where prices are currently high because of distance from primary supply points.

(8) Fertilizer manufacturers---who will purchase either elemental S or acid depending on location---much of the total volume of P fertilizer manufacture will be shared between Frasch S producers and agricultural chemicals affiliates of oil companies--new manufacturing operations may be established (mostly by other companies) in the Corn Belt or the Mississippi River system, to take advantage of by-product acid from power stations in the S. Illinois, Kentucky, Tennessee area (also a possibility in Ohio/W. Virginia)--before 1990, Western phosphate rock deposits may be exploited on a large scale using by-product S-values.

5. Shape of Industry in 1965

In 1965, the continental U.S. had 233 sulfuric acid plants with a total capacity of 24 million ST/yr. The details, rearranged from a study by the Battelle Memorial Institute,* are given in Table 2 and summarized in Table 3. Just over half of the capacity was located in only 6 states.

	Capacity, 1000 ST/yr.	% of U.S. Capacity
Florida	4242	17.7
Texas	2339	9.7
New Jersey	1811	7.6
Illinois	1587	6.6
California	1255	5.2
Louisiana	1118	4.7
	12352	51.5

The age distribution of the acid plants is recorded in Table 4. The age profile indicates:

- a fifth of the total capacity was built in 1937 or earlier, i.e. was at least 28 years old in 1965.
- nearly two fifths of the total capacity was added during W.W. II.
- almost no new plants were built between 1946 and 1952, while the wartime capacity was being digested.
- a steady rate of new plant additions occurred from 1952 to 1965.

Thus, at the end of 1965, 40% of the capacity might be considered relatively new, 40% could be called ageing, while 20% could be described as vintage. The latter included 62 of the 67 chamber plants still operating in 1965.

The final column of Table 4 shows the average size of plant that was built in a particular year. The year-to-year scatter in average size, which tends to reflect the purpose for which individual plants were built, masks the significant increase that occurred over a 25 year period.

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*"The Study of the Evolution of the World Sulfur Industry, 1965-1975," Battelle Memorial Institute, April 1967.

6. Changes Between 1965 and 1969

Table 5 shows, on a state-by-state basis, how the number of acid plants changed between 1965 and 1969. Not surprisingly, a large number of old chamber plants were shut down. At least 18 old contact plants were also shut down but, because new capacity was added, there was net increase of 3 contact plants from 1965 to 1969. However, the state-by-state changes were far from uniform.

States with net loss of contact plants			States with net gain of contact plants		
N.J. - 1	Ohio - 1	Wyo. - 1	Pa. - 1	Iowa - 1	Wash. - 1
Del. - 3	Ind. - 1	Col. - 1	Md. - 2	Mo. - 2	Cal. - 2
W.Va.- 1	Mich.- 2	N.M. - 1	N.C.- 2	Ark. - 1	
Va. - 1	Wis. - 1	Ariz. - 1	Ga. - 2	La. - 3	
S.C. - 1		Utah - 2	Fla.-1	Tex. - 3	

The following trends are apparent:

- Decline in N.E., Midwest and Mountain states
- Expansion in states producing P fertilizers (e.g. N.C., Ga., Fla., La.)
- Expansion in states producing petrochemicals, e.g., La. and Tex.
- Expansion on West Coast

Chamber plants account for less than 2% of total acid production and, thus, can have little effect on prospects for marketing abatement acid. Almost all of the chamber plants are more than 30 years old. Many will have difficulty in complying with pollution control regulations. It is expected that almost all of the remaining chamber plants will be shut down by 1980.

7. Analysis of Larger Plants

Table 6 shows the age distribution of the larger acid plants, with capacities of at least 100,000 ST/yr., that were operating in 1965. The corresponding capacity distribution of these plants is given in Table 7.

After digestion of the over-capacity created by W.W. II, large acid plants were built at a fairly uniform rate in such a way that each year accounts for about 4% of total capacity. This leads to a conceptual "average plant life" of about 26 years. The "average life" has a bearing on the rate at which abatement acid can enter the market because, in many cases, room for the latter may be provided by the shutdown of existing capacity.

Of the 80 plants listed in Table 6, only 56 were located in states where consumption of coal by electric utilities is significant. The 56 plants are relisted in Table 8. Their capacity is also summarized in Table 9 which also identifies the source of sulfur used to manufacture acid. It will be seen that almost three quarters of the capacity used elemental sulfur exclusively, while a further 15% used it to balance manufacture from smelter gases, spent acid or H_2S. Only 10.3% used smelter gases exclusively, while only 2.2% burned spent acid (sludge) exclusively.

The plants in Table 9 accounted for 56% of total U. S. capacity in 1965 (including all of the small plants excluded from Tables 6 and 7). Thus, each of these larger plants averaged 1% of total U. S. capacity.

Table 10 lists the 24 large acid plants located in states where coal consumption by electric utilities is insignificant. Theoretically, it would be possible to ship acid from a state in which abatement acid could be produced to another state that has a demand for acid but no potential for recovering it from utility stacks. In practice, the high transportation cost of acid would limit such shipments.

8. Possible Offtakers of Abatement Acid

The outlet for abatement acid will depend on the ability and willingness of existing acid marketers and captive producers/consumers to offtake the acid. With this in mind, Table 8 was converted into Table 11. The latter shows the identity of the companies that, given sufficient incentive, might be both willing and able to provide outlet for abatement acid.

It is of interest to compare the state totals for acid manufacturing capacity at the bottom of Table 11 with the potential for producing acid from stack gases. This is done in a generalized way in Table 12. It is realized that there are appreciable deviations from 60% load factor and 3 wt.% S coal. In spite of this, a high ratio in the final column of Table 10 indicates a probable excess of abatement potential over local acid demand. A corollary is that much of the sulfur removal from stack gas in these states will have to be in the form of a throwaway product or as elemental sulfur. A low ratio, on the other hand, is favorable to abatement acid. This situation exists in Florida, N.J. and Delaware. The situation in Florida is unique in that demand is associated with P fertilizer manufacture, that almost all acid manufactured is used captively, and that the Frasch sulfur producers are firmly established in the market. Nevertheless, the potential for producing abatement acid in Florida (which is overstated in Table 12) is small in relation to local demand. Thus, it is reasoned that utilities in specific areas in Florida that are also P fertilizer manufacturing locations are well placed to negotiate outlet for abatement acid. The matter is discussed further in Section (15). Deeper probing requires direct contacts between utilities and fertilizer manufacturers.

9. Recent Additions to Capacity

Table 13 indicates the acid plant capacity that has been built or announced from the end of 1965 through March 1971. The new capacity exceeds 7.2 million ST/yr., equivalent to 30% of the capacity available at the end of 1965. This suggests that new capacity is still being added at an average rate of 4%/yr. Although details are not available except in a few cases, it is also apparent that the "vintage" plants listed in Table 2 are being retired rapidly.

The geographical distribution of the new capacity, summarized in Table 14, is of interest. Unfortunately, the data for Florida are not available and the capacity for Pennsylvania is partly estimated. Recognizing that the Freeport plant in La. and the TGS plant in N. C. account, respectively, for 20.5% and 13.1% of the new capacity, it is apparent that acid manufacture is still shifting away from the Midwest, is being added steadily on the Gulf Coast, and has been added recently by smelters in the Mountain States. This is illustrated in Table 15. It will be seen that 45% of the new capacity is in three states (Miss.,La., Tex.) that use natural gas to generate electricity. When it is considered that two of these states are the Frasch sulfur producers' home base and that the third will soon be recovering large quantities of elemental S from sour natural gas, it will be recognized that this 45% of new acid capacity (reflecting local demand) has been located where the potential for using abatement acid is negligible.

Acid manufacturing capacity in the major petroleum refining states of Texas, Louisiana and California somewhat exaggerates net demand for acid. This is because a high proportion of spent acid from petroleum refining is recycled. Some acid manufacturers offer a specialized service to petroleum refiners by supplying fresh acid and collecting and reprocessing spent acid. In some cases, S values recovered in petroleum refining operations are sold to the chemical companies that supply fresh acid. In California, the so-called "bonus barrel" incentive given to petroleum refiners who produce low sulfur fuel oil is probably adding to local supplies of sulfur thereby reducing prospects for abatement acid or for smelter acid that might otherwise be supplied by Arizona.

Smelters accounted for 25% of the new capacity. Actual production would be somewhat lower because such acid plants do not often operate at full capacity. However, the location of the plants and one of their prime functions (to avoid air pollution with SO_2) make it certain that none of the new smelter acid capacity would be shutdown in order to make room for stack gas acid. To the contrary, additional smelter acid will enter the total U.S. supply before most utilities decide what form of abatement control to select.

Outside Florida, only about 13% of the new acid manufacturing capacity falls outside the areas of smelting, captive manufacture by Frasch sulfur producers, etc. This 13% is representative of the type of demand that might conceivably be filled with abatement acid in the future.

Recent additions to capacity have averaged about 1.2 million ST/yr. This quantity of acid could be produced by eight 800 megawatt power stations operating at 60% load factor on 3 wt.% S coal. However, if the incremental potential is only 13% of the incremental capacity this would be equivalent to the acid obtainable by installation of a recovery system on a single 800 MW power station each year. This projection excludes the potential in Florida and also the plant replacement possibilities suggested by Table 11. Weighing these factors as favorably as possible, it is judged that the total potential for abatement acid systems until the end of the decade may be equivalent to the acid recoverable from twenty 800 MW power stations burning 3 wt.% S coal. The potential number of installations could be much greater than twenty if applied to smaller power plants or if the coal's average sulfur content were less.

10. Applicability of Neutralizer, and Load Factor Problems

It has been suggested that a neutralizer might be installed along with an acid recovery system to provide a means of controlling the quantity of acid that would have to be marketed.

The neutralizer might be used on a day-to-day basis as a peak shaving device. However, it might also be used as a way of limiting acid production over a prolonged period of market development. In this case the use of the neutralizer would be reduced as market outlet was expanded.

The concept is very likely to be applied to smelting operations. Copper smelters in particular are likely to neutralize some dilute SO_2 gas streams in addition to making acid from other, more concentrated, SO_2 streams. In this case, the extension of neutralization to peak shave acid production would be relatively simple and should represent only a small incremental cost.

When the same concept is applied to electric utilities, a problem would be encountered. Typically, a steam generating plant achieves its maximum average load factor after about 5 years. After another 3 years or so, the load factor begins a sharp decline. Sixteen years from initial start up the local factor, typically, is only half the average at the five year point. Acid production would follow the load curve. In consequence, progressive development of outlet for acid would be frustrated by declining availability. Under these circumstances, a neutralizer might be used extensively for several years. Then, assuming some success in developing acid outlet, its further use might be limited to occasional peak shaving.**

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*"Air Pollution Control and Solid Wastes Recycling," Part 2, p. 659. Hearings before Subcommittee on Public Health and Welfare of the House Committee on Interstate and Foreign Commerce, 91st Congress.

**A hypothetical way of overcoming this difficulty, and also of sizing the electric utility's acid plant more economically, would be to start up a new power plant on low sulfur coal and then progressively switch to higher sulfur coal as acid outlet was built. In general, this approach would present coal procurement and logistical difficulties. However, there may be certain locations (e.g. in Illinois),where groups of power plants have access to both high and low sulfur coal, in which the concept could be utilized.

Over the 35 year life of the power plant, the quantity of acid sold would represent only a small fraction of the capacity of the acid plant and neutralizer. Direct neutralization without provision for any acid manufacture might be preferable.

The load curve problem is regarded as a serious deterrent to manufacturing acid. Production of a throwaway product or of elemental sulfur would be less disadvantaged because the marketing problems associated with variable, but declining, quantities of acid would be wholly or substantially avoided. Recovered elemental S, for example, could be stockpiled by the utility until a reasonable shipping parcel was available. Declining production of elemental S would not affect its marketability.

The best prospects for abatement acid appear to be in situations where the entire production of whatever quality can always be offtaken. This can occur when such production is a small fraction of local acid demand. Balancing of supply and demand can then be achieved by varying local manufacture of acid from elemental sulfur. The latter could also be used to produce oleum or to fortify abatement acid.

The concept of centralized acid recovery*, fed by magnesium sulfite from several power plants, provides a theoretical solution to the load factor problem. In so doing, however, great organizational complexity is introduced. In addition, the production rate from the central plant would be high -- a 1000 ST/D acid plant is envisaged. There is room for very few such facilities in the entire U.S. Chemico has also suggested the same concept for centralized production of elemental S**. This has considerable merit if the total costs are reasonable.

11. Acid Manufacture in the Midwest

In 1965, there were 44 sulfuric acid plants located in the East North Central region of the U.S. This is one of the areas in which coal is the principal fuel used by electric utilities and, thus, is of special interest from the standpoint of potential markets for abatement acid.

The plants are clustered around the principal industrial cities of the area such as Chicago, Detroit, Cleveland, Columbus, Cincinnati and E. St. Louis. In addition, there are a few, relatively small, fertilizer acid plants outside the major cities. It is apparent that local demand for acid is satisfied by local manufacture.

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*The concept has been advanced by the Chemical Construction Co. (Chemico). e.g. as described during Hearings before Subcommittee on Public Health and Welfare of the House Committee on Interstate and Foreign Commerce, 91st Congress: "Air Pollution Control and Solid Wastes Recycling," Part 2, pages 655-662.

**"Chemico World," September 1971; "Stack Gas Scrubbing vs. Fuel Oil Desulfurization."

The age profile of the E.N.C. plants in 1965 was:

	Start-up or Last Expansion
1937 or earlier	22
W.W. II	11
1950	1
1956	2
1960	1
1962	1
Not known	6

By 1969, five contact plants and all the chamber plants except two in Illinois had been shut down leaving a total of 32 operating plants.

Both the overall age of the E.N.C. plants and the number built during the W.W. II era are evident. Shut down of older plants is sure to continue, and this should create the need for new capacity that might be filled with abatement acid. On the other hand, the munitions - oriented plants may not be replaced, thereby limiting the rate at which new capacity will be required in the E.N. Central region.

12. Statistical Data for Sulfuric Acid

U. S. production statistics for "new" sulfuric acid, for the years 1964-1969, are given in Table 16. The "new" acid includes that obtained by burning acid sludge; this is equivalent to about 450,000-500,000 LT of sulfur per year. For example, in 1968, new acid production was 27.4 million ST of acid. Industry sources suggest that about 0.5 million ST of acid may not have been counted in the figures published by the Department of Commerce, i.e. the true total was 27.9 million ST. This is equivalent to 8.5 million LT of sulfur. Subtracting 0.5 million LT of sulfur recovered from acid sludge gives a net production of 8.0 million LT of S-values in the form of acid in 1968.

The data in Table 17 are derived from those in Table 16, but are expressed on a percentage basis to make regional trends in production more readily apparent. Expansions of phosphate fertilizer manufacture are responsible for the increases in acid production in Florida, Louisiana, and N. Carolina. Thus, the overall increase in production between 1964, and 1969 is almost entirely attributable to P-fertilizers.

Sulfuric acid is not stockpiled and, historically, very little acid has been imported or exported. Hence, the production statistics are a fair reflection of U.S. acid consumption. In spite of the expectation that industrial demand for acid will pick up after having been flat for several years, the percentages in Table 17 give a broad picture of the location of acid demand for some years to come. In fact, the data for 1969 may be summarized further:

		% of U.S. Total Production
(1)	Florida	26.2
(2)	Louisiana, Texas	17.4
(3)	S.E. Coast (Del, Md, Va, N.C., S.C., Ga)	11.2
(4)	N.E. (Pa, N.J., N.Y., Mass, Me, R.I.)	9.3
(5)	Midwest (Ill, Ohio, Mich, Ind, Wis, Minn, Iowa, Mo. Kan)	14.9
(6)	Central (Ala, Miss, Okla, Tenn, Ark, Ky, W.Va)	8.7
(7)	West Coast and other states	12.3

In the immediate future, the first 3 groups and probably (6) will continue to be natural markets for Frasch sulfur. Western Canadian sulfur will make its major penetration in (5) and may have some success in (4) and (7). However, both U.S. and Mexican Frasch producers are also expected to be active in (4). Markets in some states, e.g. Califronia, are expected to be supplied by sulfur recovered from petroleum refining and similar operations. As implied elsewhere, the eventual impact of recovered acid in areas of high acid demand will be to back out supplies of elemental sulfur from more distant primary supply points. Recovery of marketable sulfur, whether in acid or elemental form, in areas remote from industrial on fertilizer demand is not likely to be competitive with sulfur from principal supply points.

13. Sulfuric Acid Manufacture - Costs and Implications

Companies which use appreciable volumes of sulfuric acid in their own operations have the choice of purchasing acid or manufacturing it from purchased elemental sulfur. In either case tankage is required, but in the latter case a significant plant investment will also be needed. On a per ton of S-value basis (3.26 tons of 100% H_2SO_4 contain 1 ton of sulfur) the choices may be represented as follows:

- Case (1); cost per ton of S-value, (S_1) = 3.26 x delivered price of purchased acid.
- Case (2); cost per ton of S-value, (S_2) = delivered price of elemental S + cost of manufacturing acid + prorated "cost" of investment in acid manufacture.

Using data published by the Sulphur Institute, and converting to a 1970 cost basis, it may be calculated that the last two terms underlined in the second equation amount to about $15/LT* of S-value, i.e.

(S_2) = delivered price of elemental S + 15

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- Applicable to 600 ST/D plant, 330 days/yr operation, and 10% after tax R.O.I. assumed for acid plant and offsites. The Sulphur Institute, Technical Bulletin No. 8.
- Comprable estimates of manufacturing costs are given in "Sulfur and SO_2 Developments," A.I.Ch.E. Chemical Engineering Progress Technical Manual, 1971: "Economics of Sulfuric Acid Manufacture", J. M. Connor, Chemical Construction Company.

For the purpose of illustration, it is assumed that $S_2=S_1$. Then, if the delivered price of elemental sulfur is E per long ton and the delivered price of purchased acid is A per long ton*:

$$3.26A = E + 15$$

In practice, the sulfuric acid consumer may decide to purchase, rather than manufacture, acid if 3.26A is less than E + 15.

At this point, we may consider a sulfur recovery operation in the general location of the acid consumer. Let us assume that the cost of recovering sulfur in elemental form is X, and in the form of acid is Y per LT of S-value. Let us assume, further, that the cost of transporting elemental sulfur from recovery plant to the acid consumer is T per LT. Then, as a first approximation, the cost of transporting 1 LT of S-value in the form of acid will be about 4T.

Thus, the plant netback for the sulfur recovery (excluding marketing expenses other than transportation costs) is (E-T) for elemental sulfur, and (E+15 - 4T) for acid. Hence, in this simplified, generalized case, it will be advantageous to recover sulfur as acid if (E-15 - 4T - Y) is greater than (E-T-X). This is the same condition as (Y-X) being less than (15-3T). For very short distances, i.e. "local" deliveries, T will be about \$3/LT and (15-3T) will be about \$6 per long ton of S-value.

The differential of recovering a ton of S-values as acid and as elemental sulfur, (Y-X), is likely to have a negative value if the form of sulfur to be recovered is SO_2 and a positive value if the form is H_2S. If (Y-X) is negative it must be less than (15-3T) for local deliveries (since the latter will be about \$6 per long ton of S-value). If (Y-X) is positive, or if appreciable delivery distances are involved, recovery as elemental sulfur may be the better choice.

In a purely hypothetical case in which E=25, T=2, and SO_2 is recovered as acid, at a cost of \$25/LT acid equivalent, i.e., Y=25, the gross profit on recovered acid sales (E+15 - 4 T - Y) would be \$3/LT of S-value. However, if SO_2 were recovered as elemental S at the same cost, i.e. X=25, there would be a net loss of \$3/LT of elemental sulfur. This bias in favor of recovering acid rather than elemental sulfur depends on the existence of purchasers of acid near the recovery plant willing to offtake all the acid produced.

Not considered yet is that purchasers of acid may require a specific strength, and that some may require oleum and others 100% H_2SO_4 etc. It would be difficult, or expensive, to supply different grades of acid out of a single recovery plant. Furthermore continuity of supply, or rate of production, would depend on the operations of the utility company or other source of abatement sulfur. As discussed earlier, this suggests that producers of recovered acid may sell their by-product at a discount either to a regular marketer (and manufacturer) of acid, oleum, SO_2 etc., or sell by special contract to a large individual user of acid. In the latter case, stand-by or make-up supplies of acid would probably be arranged with a regular acid marketer/manufacturer.

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*\$ A per LT is equivalent to \$0.893 A per ST.

In the hypothetical case cited above, the gross profit on acid sales was calculated to be $3/LT of S-value. Moving this production through an acid reseller might well eliminate this margin. Nevertheless, for local sales, the reseller acid route might be better than recovering elemental sulfur, which would also entail marketing costs.

Next, it is necessary to consider the recovery of sulfur in a non-marketable form. Let us assume that the cost of such recovery together with the cost of disposing of the by-product (e.g. calcium sulfate) is Z per LT of S-value. Let us assume further that the marketing costs* associated with selling recovered acid or recovered elemental sulfur are respectively M_2 and M_1, and that the cost of disposing of by-product gypsum is M_3. Then we can write down the realizations for three basic cases:

- recovered elemental sulfur case: $(E-T-X-M_1)$
- recovered acid case: $(E+15-4T-Y-M_2)$
- non-marketable by-product case: $-(Z+M_3)$

The best choice will be the most positive (or least negative) of these three realizations. The third case will always be negative because a waste by-product is bound to be a charge against the parent operation. Even so, the third case may be less costly than the first two if E is low or if T, X, Y, M_1, and M_2 are high. E and T will vary considerably with location in the U.S.. E will depend on transportation costs from major supply points, e.g. Frasch sulfur from the Gulf Coast and sulfur recovered from sour gas in Alberta. T will depend on transportation costs from the point of "abatement sulfur" recovery to points of sulfur demand. These choices are summarized in Table 18.

It is certain that recovery as acid will be the best (i.e. lowest net cost) solution in some specific cases. However, it also seems likely that recovery as elemental sulfur and as a non-marketable by-product will each be best in other specific cases. Regional supply/demand considerations, transportation costs, and marketing capabilities must be considered when analyzing the best recovery approach in specific, future situations.

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*Which may be either direct marketing costs or discounts given to a reseller, and are expressed in terms of $/LT of S-value.

14. Discussion of Sulfuric Acid Prices and Implications for Abatement Acid

Approximately one-third of a ton of elemental sulfur is required to make one ton of 100% sulfuric acid. The cost of sulfur is one of the two principal elements in the cost of sulfuric acid. The other is the return on the investment (in the acid plant) needed to justify manufacture of acid. There is no fixed or unique figure that can be assigned to required return on investment. However, for an established commodity such as H_2SO_4, it is probably between 10% and 20% before taxes. From the standpoint of a potential new entrant into the acid manufacturing business, the required R.O.I. should be at least equal to that obtainable by alternate uses of capital. This suggests the upper end of the above range of R.O.I., i.e., about 20% before taxes.

One of the circumstances under which new entrants might be attracted into the business of manufacturing and marketing sulfuric acid is if the cost of sulfur were to decrease in relation to the market price for acid. This is examined in a preliminary way in Table 19 for the period 1952-1966. It will be seen that there was a slight uptrend in the current dollar price of sulfur (Column A). Column (B) merely lists the result of multiplying the figures in Column (A) by 0.307 in order to obtain the cost of elemental sulfur needed to manufacture one ST of 100% acid. Column (C) records the list price of acid, while Column (D) nets out the cost of sulfur from this price. Thus, (D) is a measure, in current dollars, of the gross revenue available to cover the cost of manufacture (exclusive of S cost) and to provide a return on the manufacturing operation.

At this point it is necessary to call attention to two additional factors. The first is that inflation was occurring, thereby offsetting the real value of the increase in (D) between 1952 and 1964. When normalized via the GNP deflator (Column E), the constant 1958 dollar value of D, in the final column, hardly changed between 1952 and 1966. The other factor is that improvements in acid manufacturing technology occurred, thereby reducing manufacturing costs*. However, this lowering of manufacturing costs was associated with increases in plant capacity. This is of greater value to an existing manufacturer (who, eventually, will replace an older plant with a larger new one) than to a potential new entrant. The difficulty facing the latter is that during the time required to establish market position he will not be able to operate the plant at full capacity, so the potential of lower unit manufacturing costs will not be realized. Furthermore, in the specific case of sulfuric acid, adequate market outlet for a large, new plant will be difficult to establish. This is because high transportation costs effectively limit the marketing area of a given acid plant.

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*This was true for chemicals as a group. The Wholesale Price Index for Chemicals and Applied Products averaged 95.0 in 1952 and was essentially unchanged at 96.7 in 1964.

The overall inference is that the period 1952-1966 was quite stable and moderately favorable to existing sulfuric acid manufacturers but offered no special attractions to potential new entrants into the business.

The situation since 1966 is examined in Table 20. From columns (A) and (C) it will be seen that acid prices moved up as sulfur prices increased, but did not come down when the latter decreased. The apparent decrease in acid price from $34.7/ST in 1969 to $30.8/ST in 1970 is probably not real. A different pricing basis was introduced in the latter year as shown in the lower part of the table. Based on the changes in W. Coast acid prices, from $32.30/ST on 8/7/67 to $35.80/ST on 12/28/70, it seems likely that the E. Coast price of $33.75/ST should have been used instead of the Gulf Coast price of $30.75 for continuation of the figures in column (C) beyond 1969. In any case, the more recent figures are "low" prices, whereas the earlier list prices are the average of "low" and "high" during the year. Thus, it appears that no list price decrease for acid occurred on a current dollar basis.Ø

The price movements since 1952 are recapitulated in summary form in Table 21, making the assumption that acid prices have not decreased since 1969. On this basis, it appears that (D) has increased significantly since 1966. The immediate inference is that either existing manufacturers will reduce acid prices or that new manufacturers will be attracted into the business. However, when construction costs are normalized against the GNP deflator, it may be seen that their rate of inflation is higher than the rate for the economy as a whole. In fact, the differential for the past few years has run about 3%/yr. ahead of the general rate of inflation. This is a strong deterrent to capital investment by potential new entrants into commodity chemical manufacturing*.

Theoretically, the Frasch sulfur producers are potential new entrants into the sulfuric acid business. Indeed, the two largest producers operate large acid plants already. However, such operations are a captive part of diversification into the manufacture of phosphate fertilizers. To enter the merchant acid business would place the Frasch producers in competition with their principal customers for elemental sulfur. Also, it would require significant investment capital that is needed to speed diversification into other minerals.

For the above reasons, there is no immediate pressure on U. S. acid manufacturers to reduce prices. Nevertheless, this may happen for the reasons discussed below.

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* This is confirmed by recent upward movement in the Wholesale Price Index for Chemicals and Allied Products: 1969=99.9, March 1971=104.5.

Ø This is confirmed by Nelson refinery operating cost data for sulfuric acid.

By-product acid has a localized and minor effect on acid markets as a whole. In some ways the current acid picture parallels that for elemental sulfur before W. Canadian recovered S became the dominant factor in several U. S. regional markets.

Stepped up recovery of acid from U. S. smelters will affect acid prices in tributary markets within the next few years. However, acid prices in general will not necessarily be affected. Of potentially greater significance are the enormous quantities of acid scheduled to be recovered in the Sudbury area of Ontario. The quantity could reach several million tons of S equivalent by 1980. Only a fraction of the acid can be absorbed in E. Canadian markets. Consequently, very large scale movements to Europe and the eastern U. S. are being considered. Because U. S. markets already have adequate supplies of acid, it is clear that certain areas (with which economic transportation linkages can be established) could come under intense pressure.

So far, the discussion has been in terms of list prices for sulfuric acid. In Table 22, however, the latter are compared with Department of Commerce data. It would appear that the list prices reflect trends, but may overstate actual prices by an average of more than $7/ST.

The fact that there are approximately 200 sulfuric acid plants in the continental U.S. is a reflection of the need to be located close to demand points in order to minimize transportation costs. This is also an explanation of why the average size of acid plant varies from state to state. This is examined in Table 23 in terms of the average production of acid per plant in 1968. The low average of 49 ST/CD in S. Carolina is attributable to the half dozen chamber plants in that state. The 1188 ST/CD for Florida reflects the state's preeminence in phosphate fertilizer manufacture.

The value of acid shipments by state or area, for 1967 and 1968, is given in Table 24. In general, the price differences among states are compatible with delivered costs of elemental sulfur to the respective states. However, plant size is also a factor, particularly in Florida.

Table 25 illustrates an extremely important aspect of the U. S. acid industry, namely that a high percentage of manufacture is for captive use. The percentage ranges from about 7 in Pennsylvania to more than 90 in Florida. The average outside Florida is about 40%. This means that a utility planning to produce abatement acid would have two hypothetical types of customer:

(1) An existing acid marketer, who would merchant the abatement acid in combination with his own production (from elemental sulfur in most cases).

(2) A captive user of acid who wanted to shut down part of his own production or wanted to obtain incremental acid without installing new manufacturing capacity.

What might either of these potential off takers be prepared to pay? In either case, the abatement acid would have to be competitive with acid deliberately made from elemental sulfur. 1975 price assumptions for the latter are approximately:

ex Canada	
F.O.R. Alberta	$10/LT
F.O.B. Vancouver	$17/LT
del. Chicago	$27/LT
ex U.S.	
F.O.R./F.O.B. Gulf	$18-23/LT
del. Chicago	$23-28LT

Having regard to the capital and operating costs for acid manufacture, and the need for return on investment:

- When an existing producer of acid (from elemental S) must decide whether to build a new plant or to purchase acid--he may choose to purchase if the delivered acid price is significantly less than $8/ST plus the cost of S--a projected total of about $16/ST for Chicago in 1975, but lower in many other locations.
- For an existing producer to shut down his own plant, acid would have to be delivered for about $6.50/ST less than in the above case.
- Abatement acid may have to be purified, fortified, etc., thereby lowering the price an offtaker would be prepared to pay.

In the first case the net-back to an abatement acid producer might be as much as $9/ST--or more in exceptional cases where the off-taker could receive the acid by pipeline* from the producer (e.g., electric utility). In the second case the net-back might be as much as $2/ST. In either case the net-back would be reduced if:

- Elemental S were available for less than $23/LT (reduce acid value by $1/ST for each $3/LT drop in S price).

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*"Under the fence" to a neighboring plant.

- Offtaker is distant from the acid producer (reduce acid value by \$1/ST for each 100 miles beyond the first 100 miles).

- Purification or fortification costs were significant.

Thus, negative net-backs to a producer of abatement acid are possible. It is stressed that net-backs as high as \$9/ST and \$2/ST in the two cases discussed above would probably be obtainable in a few cases only, and the average net-back would be much lower. There are strong indications that the near to mid-term market for abatement acid will be small. The quantity will depend on the ability and willingness of existing acid marketers and captive producer/consumers to offtake abatement acid. Even with such cooperation, the rate at which abatement acid can be absorbed will be slow. For many of the states that have coal-burning utilities, the amount of abatement acid that could be accommodated by the market could be recovered from a single, large power plant.

The advantage to the user of acid of being able to purchase it directly rather than manufacturing it from elemental S is taken account of in the computer calculations of the Sulfur Model by applying an "acid equivalency" credit to the minimum delivered price. The credit is relatively small in 1975 and 1980, thereby simulating the need to price abatement acid low enough to provide the incentive for shutting down existing capacity. In 1985 and subsequently, the credit is much higher reflecting the expected evolution of markets for merchant acid in the U. S.

Special situations, brought about by concentrations of petroleum refining and/or phosphate fertilizer manufacture, make it impractical to perform generalized calculations of abatement acid value for California, the Gulf Coast and Florida. Also to be excluded from generalized calculations are cases in which an electric utility may be located close to smelters that already market acid (or will do so by 1975). Once such marketing arrangements are in effect, it is considered unlikely that any electric utility could enter the same market with abatement acid.

15. Phosphoric Acid, Phosphate Fertilizers and Implications for Abatement Acid

A general account of the elemental phosphorus and phosphate fertilizer industries is given on pages 4-43 to 4-54 of Senate Document No. 92-6*. The account may be used as a starting point for discussing the over-capacity that has existed in the phosphate fertilizer industry, how this situation is changing, and the implications for sulfuric acid.

First, it should be noted that the industrial demand for phosphates is related to their use in detergents and that phosphates have been implicated in eutrophication in rivers, lakes, etc. This has produced pressures to eliminate phosphates from detergents or markedly reduce their percentage in detergent formulations. In turn, this has reduced the demand for industrial phosphates and has created the possibility that alternative outlet would be sought in P fertilizers, thereby contributing further to over-capacity in that industry.

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*"The Economics of Clean Air," report of the Administrator of the E.P.A. to Congress, March 1971.

The Economic Research Service of the U.S.D.A., in its "Fertilizer Situation" for March 1971, commented:

> "Capacity for producing processed fertilizer P_2O_5 totals about 6.4 million tons....about 3.1 million tons of this capacity is in ammonium phosphates, 2 million in TSP, and 1.3 million in NSP. Wet process phosphoric acid capacity is about 5.5 million tons of P_2O_5 and is not expected to increase during 1971. ...Thus, capacity to produce P_2O_5 in 1971 will exceed 1969/70 use by close to 40%."

Excess capacity was also referred to in the New York Times of June 14, 1971, commenting on the Brewster Phosphates partnership between American Cyanamid and Kerr McGee and their tolling arrangement with Freeport Minerals to use 50% of the capacity of the latter company's plant at Uncle Sam, Louisiana. In addition, the Times' article stated

> "The industry-wide over-capacity problem was corrected by way of attrition. At least 10 phosphoric acid plants with an annual capacity of 750,000 tons have been shut down since 1960." (emphasis added)

The word "was", underlined above, is probably not correct, i.e., over-capacity still exists in spite of plant shutdowns. Nevertheless, industry is bringing the situation under control. This is in contrast with EPA's projection for FY 1976 cited in the lower half of Table 26. Far from a 54% utilization of P_2O_5 production capacity in FY 1976 it is probable that capacity will be tight, perhaps as early as 1972/3. This has a bearing on potential outlets for abatement sulfuric acid as will be discussed later.

Rising electricity costs and the age of many electric furnaces used to make elemental S are causing the shutdown of such capacity. This will limit the potential diversion of furnace acid to P fertilizer production (see Table 27).

Production of NSP is declining, partly because it is usually more economical to fertilize with DAP or TSP and partly because much of the NSP production has been associated with small, and now obsolete, sulfuric acid plants in the Eastern U.S. Many such plants have been shut down already. Additional shutdowns will occur in cases where it will not be economically feasible to bring the acid plants into compliance with air pollution control regulations. Thus, the industry trend is away from NSP (16-22% P_2O_5) and towards TSP (typically 46-47% P_2O_5) and DAP (approx.

46% P_2O_5) - particularly the latter because of its higher total nutrient content. In consequence, with the shut down of some phosphoric acid capacity (needed to make DAP), available capacity will soon be tight. When this occurs, additional phosphoric acid capacity will be constructed. In turn, this will create a demand for sulfuric acid in large unit volumes. The capacity situation, as it existed in 1967, is summarized in Table 28.

Details of 1967 wet process phosphoric acid capacity are given in Table 29 and summarized in Table 30. Freeport's Uncle Sam plant is included in this tabulation even though it did not come on stream until the following year. Excluding this plant, the total U.S. capacity in Table 30 is 4.94 million metric tons of P_2O_5 or 5.44 million ST. The latter figure checks the current capacity cited by the U.S.D.A. but is slightly less than the 5.86 million ST of orthophosphoric acid capacity reported in Table 28. The small discrepancy may be due to different assumptions made when converting from daily to annual capacity. As the difference is slight, it appears that the 47 wet process plants in Table 29 are a reasonably complete listing. The figure of 47 (or 46 excluding Freeport's plant) should be contrasted with the 179 P_2O_5 plants noted in Tables 26 and 27. Some of the numerical difference may be due to multiple installations at the same location. In the main, however, the other 133 plants must represent facilities for manufacturing TSP and NSP.

Almost all of the wet process phosphoric acid capacity has been built since 1960. This is a reflection of a rapid change in fertilizer technology from NSP to DAP. However, it also means that, unlike the average age of sulfuric acid plants in 1967, U.S. phosphoric acid capacity is modern. With the exception of American Cyanamid's Brewster plant, it is expected that that most of the 10 plants, totaling 750,000 ST capacity, referred to in the Times' article will have been the smaller, older plants listed in Table 29 and will include some plants that made industrial (not fertilizer) phosphoric acid. This will have had the effect of further increasing the percentage of P acid made from captively produced sulfuric acid. Treating the tolling arrangement at Uncle Sam as equivalent to a captive operation, it is believed that approximately 95% of wet process P acid is now made from captively produced sulfuric acid. 80% of this capacity is located in the S.E. (Florida, Louisiana, Texas, Mississippi, North Carolina). In turn, this is equivalent to more than 40% of the total U.S. demand for sulfuric acid. Undoubtedly, acid demand will increase in this area.

From the standpoint of potential outlet for abatement acid, a major problem is that few coal-burning electric utilities are located close to demand for fertilizer acid. In Florida, the latter is concentrated in the Tampa/Bartow area. However, Tampa Electric's F.J. Gannon 1270 megawatt plant is well located, while Florida Power Corporation's 440 MW plant at Crystal River is only about 70 miles from the phosphate processing area*. In spite of the general practice of producing H_2SO_4 captively, the large and expanding demand in the Tampa/Bartow area should make it feasible for outlet for abatement acid to be negotiated. Prospects in the other four states (Texas, Louisiana, Mississippi, North Carolina) are far less favorable.

16. Fuel Sulfur Content May Affect Choice of Abatement System

There may be a "fit" of fuel sulfur content with different types of abatement system. The reasoning is entirely qualitative. Investment and operating cost data for different abatement systems would be required for more detailed analysis.

At one end of the scale, fuel sulfur content will be so low that there will be no need for any system to abate SO_x emissions. This will be the case whenever natural gas is burned and also in a (limited) number of cases where oil or coal of sufficiently low S content is available.

With the next step up the sulfur scale there will be a need only to "trim" SO_x emissions to meet air quality standards. This may occur with either coal or oil when fuel S content is low, yet not quite low enough to meet the standards without some stack gas treatment. Lime injection may meet this situation by providing a modest reduction in SO_x emissions, and with a minimum capital investment in an abatement system.

Acid recovery systems may be best suited either to medium-sized power plants burning high S coal or to larger power plants burning medium S coal. The latter case is more favorable since large power plants are likely to be operated at a higher and more uniform load factor. However, if a large power plant were to burn high S coal it might have the capability of producing more acid than could be marketed locally. Thus, relatively favorable conditions for acid production are sandwiched between:

- Low S fuel or small power plants, that would not generate enough acid to compensate for the extra effort needed to market it.
- High S fuel burned in large power plants, that would generate more acid than could be marketed locally.

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*Other coal-burning electric utilities at Pensacola, Chattahoochee and Panama City are not well located with respect to the principal P fertilizer manufacturing area. On the other hand, two of Florida Power Corporation's power stations, Bartow (494 MW) and Higgins (138 MW), fire both oil and gas, with the former representing some potential for producing abatement acid. In addition, Tampa Electric's Hookers Point (218 MW) and Knight (64 MW) plants are both oil-fired.

Next, there will be the case of high S coal burned in large power plants. This favors recovery of elemental S. The reasons include:

- The advantage of producing elemental S in significant quantities, thereby favoring the arrangement of economical transportation to points of demand.
- The relative advantage over waste gypsum of having a smaller quantity of by-product to store and dispose of.
- The possible future advantage of being able to negotiate buy-back of S with the fuel supplier.

Finally, there will be cases in which (1) no control, (2) simple injection, (3) acid recovery, and (4) elemental S recovery are not appropriate. The various scrubbing processes may be applicable. This will usually be the case when neither (1) nor (2) is appropriate and neither acid nor elemental S can be delivered economically. Land-locked locations (e.g. with no access to barge transportation) such as mine-mouth power plants or those fed by slurry pipelines will be particularly disadvantageous to systems that recover S in useful form.

TABLE 1

U.S. CORPORATIONS INVOLVED IN THE MARKETING OF SULFUR, SULFURIC ACID, ETC.

Corporation	Sulfuric Acid	Oleum	Liquid SO_2	Sulfur					
				Crude	Refined	Agricultural	Colloidal	Precipitated	Wettable
Agrico (Continental Oil)	X								
Air Products			X						
Allied Chemical	X	X	X					X	
American Cyanamid	X	X							
Arco Chemical				X				X	
American Zinc	X								
Ansul Co.			X						
Baker J. T.	X		X						
Cities Service	X		X						
Chemical Formulators						X			
Chempar Chemical						X			
Collier Carbon	X			X		X			
Columbia Nitrogen	X					X			
Corco Chemical	X	X							
Diamond Shamrock	X					X			
DuPont	X	X							
DUVAL				X					
Dow Chemical			X						
Eagle Pitcher	X								
Eastman Kodak	X								
Electronic Space Prods.					X			X	
Essex Chemical	X		X						
Freeport Minerals	X			X					
Georgia Pacific	X								
Grace	X					X			
Gulf Oil	X			X					

Based on "Chemical Week" Buyers Guide, 1971.

TABLE 1 (CONT'D)

Corporation	Sulfuric Acid	Oleum	Liquid SO_2	Sulfur Crude	Refined	Agricultural	Colloidal	Precipitated	Wettable
Huisking Chas.								X	
Kerr-McGee	X								
Los Angeles Chemical						X			X
Mallinckrodt Chemical	X							X	
Marion Manufacturing	X	X							
Marathon Oil							X		
Merck	X							X	
Monsanto	X		X						
Mobil Chemicals				X	X				
National Zinc	X	X							
N.J. Zinc	X								
Olin Corp.	X				X	X	X	X	X
Pemwalt Corp	X								
Parramore & Griffin					X	X			X
Reagent Chemical				X	X	X			X
Reichhold Chemical	X								
Rohm & Haas	X								
Royce Chemical			X						
St. Joe Minerals	X								
Stauffer Chemical	X	X	X		X				
Shell Chemical				X					
Signal Oil & Gas				X				X	
3M Co.	X								
Texas Gulf Sulphur				X					
Uniroyal	X								
U.S. Industrial Chem.	X	X							
United Mineral					X				
U. S. Steel	X								
Virginia Chemical			X						
Wilson Pharmaceutical	X								

TABLE 1 (CONT'D)

Corporation	Sulfuric Acid	Oleum	Liquid SO_2	Sulfur Crude	Sulfur Refined	Sulfur Agricultural	Sulfur Colloidal	Sulfur Precipitated	Sulfur Wettable
Distributors									
Agvar Chemicals	X								
Ashland Chemical	X								
Chemtech Corp.	X								
ICI America	X		X						
Inland Chemical	X								
Jones Chemical	X		X						
McKesson Chemical	X		X		X	X		X	X
Prior Chemical	X								
Shepard Chemical				X					
Sylvan Chemical									X
Textile Chemical	X								
Thompson-Hayward	X	X	X		X	X		X	X

TABLE 2

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 ST/yr	Merchant	Captive	Source of Sulfur
Maine	1942 (1956)	Northern Chem. Ind.	59		✓	S
Mass.	(2)	Continental Oil Co.	27 (3,8)		✓	S
	(2) (1942)	Monsanto	127	✓		S
R.I.	(2)	Heyden Newport Chem.	18	✓		S
			231			
N.Y.	(2)	Continental Oil Co.	45 (3,8)	✓	✓	S
	(2) (1941)	Allied Chem.	181	✓	✓	(4) + S
	(2)	Eastman Kodak	6	✓	✓	S
			232			
N.J.	(2)	Continental Oil Co.	45 (3,8)		✓	S
	1958	Allied Chem.	191	✓	✓	(4) + S
	1945	Am. Cyanamid	58		✓	S
	(2)	Am. Cyanamid	179	✓		S
	(2)	Armour	27 (3,8)		✓	S
	1959	Dixon Chemical	272	✓		S
	(2)	Du Pont	67		✓	S
	(2)	Du Pont	91		✓	S
	(2)	Du Pont	272		✓	S
	1956	Essex Chemical	136	✓	✓	S
	(2) (1942)	Nat. Lead	454		✓	S
	1946	Koppers	19		✓	S
			1811			
PA.	(2) (1941)	Allied Chem.	218	✓		(4) + S
	1945	Arco	40 (7)		✓	(6)
	1941	Du Pont	68	✓		S
	(2)	New Castle Chem.	10 (3,7.8)	✓		S
	(2)	N. J. Zinc	159		✓	(5)
	1945	Pittsburgh Coke	40 (7)	✓	✓	S
	(2)	Rohm and Haas	73		✓	S
	(2)	St. Joseph Lead	200			(5) + S
	(2)	U. S. Steel	104 (3,8)	✓	✓	S
	1959	C. K. Williams	6	✓		(5)
	(2)	Witco Chem.	32		✓	(4) + S
			950			

TABLE 2 (cont'd)

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 ST/yr	Merchant	Captive	Source of Sulfur
Md.	(2)	Continental Oil Co.	31 (3)		✓	S
	(2)	Kerr McGee	95 (3)	✓		S
	(2) (1946)	Olin	318 (3)	✓	✓	S
			444			
Del.	1942	Allied Chem.	295	✓	✓	(4)
	--	Bethlehem Steel	91		✓	(5)
	(2) (1945)	Grace	272	✓	✓	S
	(2)	Royster Guano	36 (3,8)		✓	S
	(2)	U. S. Naval Powder	18 (7)		✓	S
			712			
Va.	(2)	Continental Oil Co.	40 (3)		✓	S
	1941	Allied Chem.	145	✓		S
	1965	Allied Chem.	136	✓	✓	S
	(2)	Allied Chem.	113	✓		S
	(2) (1942)	Am. Cyanamid	27		✓	S
	1946	Du Pont	82		✓	S
	--	Grace	20 (3)			S
	1940	Hercules	23		✓	S
	(2)	Robertson Chem.	12 (3,7)		✓	S
	(2)	Royster Guano	20 (3)		✓	S
	(2)	Borden Chem.	66		✓	S
	1946	Swift	42		✓	S
	(2)	Virginia-Carolina	18 (3)		✓	S
	(2)	Virginia-Carolina	32 (3)		✓	S
	--	Weaver Chem.	32		✓	S
			808			
W. Va.	1946	Allied Chem.	122	✓	✓	S
	(2)	Union Carbide	19		✓	S
			141			

TABLE 2 (cont'd)

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 ST/yr	Merchant	Captive	Source of Sulfur
N.C.	(2)	Acme Fertilizer	18 (3)		✓	S
	--	Continental Oil Co.	19 (3)		✓	S
	(2)	Armour	16 (3)		✓	S
	(2)	Armour	32 (3)		✓	S
	(2)	Swift	32 (3)		✓	S
	(2)	Virginia-Carolina	24 (3)		✓	S
	(2)	Virginia-Carolina	7 (3)		✓	S
	(2) (1942)	Virginia-Carolina	25		✓	S
	1964	Wright Chemical	48		✓	S
			221			
S.C.	(2) (1946)	Continental Oil Co.	27 (3)		✓	S
	(2)	Anderson Fertilizer	14 (3)		✓	S
	(2)	Grace	36	✓	✓	S
	1946	I.M.C.	18		✓	S
	(2)	Planters Fertilizer	23 (3)		✓	S
	(2)	Royster Guano	11 (3)		✓	S
	(2)	Virginia-Carolina	28 (3)		✓	S
	(2)	Virginia-Carolina	5 (3)		✓	S
			162			
Ga.	1945	Continental Oil Co.	18 (3)		✓	S
	--	Am. Cyanamid	204	✓	✓	S
	(2)	Armour	18 (3)		✓	S
	(2)	Armour	16 (3)		✓	S
	(2)	Cotton States Fert.	10 (3)		✓	S
	(2)	Georgia Fert.	18 (3)		✓	S
	--	Minerals & Chem. Philipp	32		✓	S
	(2)	Pelham Phosphate	23 (3)		✓	S
	(2)	Royster Guano	23 (3)		✓	S
	(2)	Royster Guano	9 (3)		✓	S
	--	Smith Guano	16 (3)		✓	S
	(2)	Southern Fert.	36		✓	S
	(2)	Southern States	32 (3)		✓	S
	(2)	Virginia-Carolina	7 (3)		✓	S
	(2)	Virginia-Carolina	18 (3)		✓	S
			480			

TABLE 2 (cont'd)

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 ST/yr	Merchant	Captive	Source of Sulfur
Fla.	1963	Acid Inc.	476	✓		S
	(2)	Continental Oil Co.	38 (3)		✓	S
	1945 (1965)	Continental Oil Co.	381		✓	S
	-- (1961)	Am. Cyanamid	499		✓	S
	1942	Armour	136		✓	S
	1962	Armour	363		✓	S
	(2)	Armour	18 (3,7)		✓	S
	1960	Grace	476		✓	S
	1957	I.M.C.	454		✓	S
	--	Royster Guano	68		✓	S
	--	Swift	190		✓	S
	(2) (1945)	Cities Service	817		✓	S
	1945	Virginia-Carolina	113		✓	S
	1959	Virginia-Carolina	159		✓	S
	--	Wilson & Toomer Fert.	18 (3)		✓	S
	(2) (1946)	Wilson & Toomer Fert.	36 (3)		✓	S
			4242			
Ohio	1960	Continental Oil Co.	40		✓	S
	(2) (1946)	Continental Oil Co.	16 (3,8)	✓	✓	S
	(2)	Continental Oil Co.	32 (3,8)	✓	✓	S
	(2) (1941)	Allied Chem.	113	✓	✓	S
	--	Am. Cyanamid	63	✓	✓	S
	(2)	Armour	18 (3,8)		✓	S
	1950	Diamond Fertilizer	11	✓	✓	S
	1956	Du Pont	159	✓	✓	S
	(2)	Du Pont	181	✓	✓	S
	(2)	Farmers Fert.	24 (3,8)	✓	✓	(5) + S
	1946	I.M.C.	41		✓	S
	1940 (1942)	3-M	64	✓	✓	S
	(2)	Royster Guano	18	✓	✓	S
	(2)	Borden Chem.	18		✓	S
	(2)(1942)	Virginia Carolina	14		✓	S
			812			

TABLE 2 (cont'd)

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 ST/yr	Merchant	Captive	Source of Sulfur
Ind.	(2) (1942)	Du Pont	295	✓		S
	1946	Marion Manufact.	54	✓		S
	(2) (1956)	Stauffer	109	✓		S
	(2) (1941)	Stauffer	250	✓		S
			708			
Ill.	--	Continental Oil Co.	14 (3)		✓	S
	1945	Continental Oil Co.	23 (3)		✓	S
	(2) (1941)	Allied Chem.	118	✓	✓	(4) + S
	(2) (1956)	Allied Chem.	163	✓	✓	(4) + S
	(2)	Am. Zinc	14 (3,7)			(5)
	1945	Am. Zinc	105	✓		(5) + S
	(2)	Am. Cyanamid	54	✓	✓	S
	(2)	Armour	32 (3)		✓	S
	1945	Kanakee Ordnance	66		✓	S
	(2)	Matthiesen & Hegeler	35(3)	✓		S
	(2) (1942)	Monsanto	254	✓		S
	1956	Nat. Distillers	127		✓	S
	1962	Occidental Petroleum	191		✓	S
	1942	Olin	318		✓	S
	--	Borden Chem.	32		✓	S
	1942	Swift	36	✓		S
	--	C.K. Williams	5		✓	(5) + S
			1587			
Mich.	(2)	Continental Oil Co.	23 (3,8)		✓	(6) + S
	--	Continental Oil Co.	32		✓	S
	--	Am. Cyanamid	23	✓	✓	S
	1941(1955)	Allied Chem.	181	✓	✓	(4) + S
	(2)	Detroit Chem.	10 (7)	✓		S
	(2)	Du Pont	154	✓	✓	S
	--	Grace	33			S
			456			

TABLE 2 (cont'd)

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 ST/yr	Merchant	Captive	Source of Sulfur
Wis.	1941	Badger Ordnance	54		✓	S
	(2)	Du Pont	18		✓	S
	1946	Royster Guano	33		✓	S
			105			
Ky.	(2)	Du Pont	159	✓		S
	1946	Pennsalt	41		✓	S
			200			
Tenn.	(2)	Armour	18 (3)		✓	S
	(2)	Virginia Carolina	16 (3)		✓	S
	(2) (1941)	Cities Service	762	✓	✓	(5)
	1941	Volunteer Ordnance	132		✓	S
			928			
Ala.	1947	Continental Oil Co.	25		✓	S
	(2)	Continental Oil Co.	32 (3)		✓	S
	(2)	Du Pont	11		✓	S
	(2)	Home Guano	11 (3)		✓	S
	--	Reichhold Chem.	64		✓	S
	(2) (1942)	Standard Chem.	16 (3)		✓	S
	1957	Stauffer	190	✓		(6) + S
	1940 (1950)	Cities Service	136	✓		S
	(2)	Virginia - Carolina	18		✓	S
	(2)	Virginia - Carolina	16 (3)		✓	S
	(2)	Virginia - Carolina	16 (3)		✓	S
			535			
Miss.	1958 (1962)	Coastal Chemical	227		✓	S
	1945	I.M.C.	16 (3)		✓	S
			243			
Minn.	1959	North Star Chem.	127	✓		S
Iowa	--	Continental Oil Co.	23 (3)		✓	S
	1954	I.M.C.	27		✓	S
	1946	Nat. Distillers	66	✓		S
			116			

TABLE 2 (cont'd)

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 MT/yr	Merchant	Captive	Source of Sulfur
Mo.	(2)	Grace	64		X	S
	(2) (1942)	Nat. Lead	476		X	(5) + S
			540			
Kan.	1954	Eagle Pitcher	136	X		(5)
	1940	Nat. Distillers	80	X	X	(4) + S
			216			
Okla.	(2)	Nat. Zinc	64	X		(5)
	(2) (1941)	Ozark Mahoning	106	X	X	S
			170			
Ark.	1946	Monsanto	100		X	S
	1946	Olin	95		X	S
			195			
La.	--	Am. Cyanamid	--		X	S
	1953	Allied Chem.	82	X	X	(4) + S
	(2)	Armour	16 (3,8)		X	S
	1945	Cities Service	136	X	X	(6) + S
	1945 (1965)	Occidental Petroleum	444		X	S
	(2) (1946)	Olin	77	X		S
	(2) (1952)	Stauffer	363	X		(5) + S
			1118			
Tex.	1945 (1946)	Asarco	60	X		(5)
	(2)	Armour	16 (3,8)		X	S
	1960	Du Pont	318		X	(4) + S
	(2)	Gulf	127		X	(4) + S
	(2) (1946)	Olin	82	X		S
	(2) (1941)	Olin	229	X		S
	1946	Olin	236		X	S
	1953	Shamrock	27		X	(4) + S
	1958	Borden Chem.	159		X	(4) + S

TABLE 2 (cont'd)

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 MT/yr	Merchant	Captive	Source of Sulfur
Tex. (con't)	(2) (1942)	Stauffer	109	X	X	S
	(2) (1955)	Stauffer	726	X	X	(4) + S
	1953 (1955)	Stauffer	250	X		(4) + S
			2339			
Mont.	(2) (1946)	Anaconda	109	X		(5)
Idaho	1954	Bunker Hill	109	X		(5) + S
	1959 (1965)	J. R. Simplot	349		X	S
			458			
Wyo.	-- (1960)	Susquehanna	68			S
	--	Western Nuclear	33		X	S
	1959 (1960)	Fremont Minerals	40	X	X	S
			141			
Col.	(2) (1941)	Allied Chem.	45	X		(4) + S
	1955	Rico Argentine	64	X	X	(5)
	1956	Union Carbide	36		X	S
			145			
N.M.	1962	Climax Chem.	48	X	X	(6) + S
	1958	Kerr McGee	136	X	X	S
	1955	Anaconda	32	X	X	S
			216			
Ariz.	(2)	Apache Powder	32		X	S
	--	Bagdad Copper	64		X	S
	1943	Inspiration Consol. Cop.	77	X	X	S
	1957	Kennecott	32	X	X	(5)
	1957	Southwest Agrochem.	27	X	X	S
			232			

TABLE 2 (cont'd)

U. S. SULFURIC ACID PLANTS IN 1965*

State	Start up Date (1)	Company	Capacity 1000 MT/yr	Merchant	Captive	Source of Sulfur
Utah	(2)	Garfield Chem.	363	X		(5)
	1957	Texas Zinc Min.	23		X	S
	1957	U. S. Steel	6		X	(6)
			392			
Nev.	1953	Anaconda	136	X	X	S
Wash.	1958	Allied Chem.	36	X	X	(4), (6) + S
	1948 (1950)	Asarco	45			
			81			
Calif.	(2)	Allied Chem.	109	X		(4) + S
	(2) (1941)	Allied Chem.	159	X	X	(4), (6) + S
	1941 (1945)	Allied Chem.	73	X	X	(4), (6) + S
	(2)	Asarco	14	X		(5)
	1960	Union Oil	79	X	X	(4), (6) + S
	1954	Monsanto	113	X	X	(4), (6) + S
	1957 (1965)	Occidental Petroleum	127		X	S
	(2) (1957)	Stauffer	295	X	X	(4), (6) + S
	1945	Stauffer	159	X	X	S
	1960	Valley Nitrogen	127		X	S
			1255			

NOTES FOR TABLE 2

(1) Plants may have been expanded subsequently (date in parentheses).
(2) 1937 or earlier.
(3) Chamber process.
(4) Spent acid.
(5) Smelter gases + pyrites.
(6) H_2S, including refinery gas.
(7) Estimate (for inclusion in total capacity).
(8) Shut down by 1969.
* Based on data in "The Study of the Evolution of the World Sulfur Industry 1965-1975", Battelle Memorial Institute, April 1967.

TABLE 3

U. S. SULFURIC ACID CAPACITY IN 1965

	1000 ST/YR		1000 ST/YR		1000 ST/YR
New England	231	Ohio	812	Minn.	127
		Ind.	708	Iowa	116
N.Y.	232	Ill.	1587	Mo.	540
N.J.	1811	Mich.	456	Kan.	216
Pa.	950	Wis.	105	W.N. Central	999
Middle Atlantic	2993	E.N. Central	3668		
Md.	444	Ky.	200	Mont.	109
Del.	712	Tenn.	928	Idaho	458
Va.	808	Ala.	535	Wyo.	141
W. Va.	141	Miss.	243	Col.	145
N.C.	221	E. S. Central	1906	N.M.	216
S.C.	162			Ariz.	232
Ga.	480	Okla.	170	Utah	392
	2968	Ark.	195	Nev.	136
		La.	1118	Mountain	1829
Fla.	4242	Tex.	2339		
		W. S. Central	3822	Wash.	81
				Calif.	1255
					1336

Continental U. S. (1965) 23,944

TABLE 4

AGE DISTRIBUTION AND CAPACITY OF U.S. SULFURIC ACID PLANTS AT END OF 1965

Start Up Date (1)	No. of Plants		Capacity		% of Total		Av. Capacity of Contact Plant (3)
	Total	Chamber	1000 ST/Yr	Cumulative	Year	Cumulative	
(2)	108	62	5176	5176	21.6	21.6	
1940	2	--	103	5279	0.4	22.0	81
1941	14	--	2580	7859	10.7	32.7	52
1942	15	1	2646	10505	11.0	48.7	184
1943	1	--	77	10582	0.3	44.0	188
1945	14	1	1936	12518	8.1	52.1	77
1946	21	3	1674	14192	7.0	59.1	146
1947	1	--	25	14217	0.1	59.2	89
1950	3	--	192	14409	0.8	60.0	25
1952	1	--	363	14772	1.5	61.5	64
1953	3	--	245	15017	1.0	62.5	363
1954	4	--	385	15402	1.6	64.1	82
1955	5	--	1253	16655	5.2	69.3	96
1956	7	--	789	17444	3.3	72.6	251
1957	7	--	1027	18471	4.3	76.9	113
1958	4	--	522	18993	2.2	79.1	147
1959	4	--	564	19557	2.4	81.5	131
1960	7	--	1148	20705	4.8	86.3	141
1961	1	--	499	21204	2.1	88.4	164
1962	4	--	829	22033	3.4	91.8	499
1963	1	--	476	22509	2.0	93.8	207
1964	1	--	48	22557	0.2	94.0	476
1965	5	--	1437	23994	6.0	100.	48
							287
	233	67	23994		100.		135

(1) Start up date or date of last expansion.
(2) 1937 or earlier (including plants for which no start up date is available).
(3) Counting multi-train units as a single plant.

TABLE 5

TRENDS IN NUMBER OF U.S. SULFURIC ACID PLANTS

	1965		1968		1969	
	Contact	Chamber	Contact	Chamber	Contact	Chamber
New England	3	1	3	--	3	--
N.Y.	2	1	2	--	2	--
N.J.	10	2	9	--	9	--
Pa.	9	2	10	--	10	--
Del.	4	1	1	--	1	--
Md.	1	3	3	3	3	3
Va.	9	6	8	3	8	2
W. Va.	2	--	2	--	1	--
N.C.	2	7	4	4	4	2
S.C.	2	6	1	6	1	5
Ga.	3	12	5	9	5	8
Fla.	12	4	14	3	13	3
Ohio	10	5	10	--	9	--
Ind.	4	--	3	--	3	--
Ill.	12	5	13	2	12	2
Mich.	6	1	5	--	4	--
Wis.	3	--	3	--	2	--
Ky.	2	--	2	--	2	--
Tenn.	2	2	2	2	2	2
Ala.	6	5	6	2	6	1
Miss.	1	1	1	1	1	1
Minn.	1	--	1	--	1	--
Iowa	2	1	3	1	3	1
Mo.	2	--	3	--	4	--
Kan.	2	--	2	--	2	--
Ark.	2	--	3	--	3	--
La.	6	1	9	--	9	--
Okla.	2	--	2	--	2	--
Tex.	11	1	14	--	14	--
Mont	1	--	1	--	1	--
Ida.	2	--	2	--	2	--
Wyo.	3	--	2	--	2	--
Col.	3	--	2	--	2	--
N.M.	3	--	2	--	2	--
Ariz.	5	--	4	--	4	--
Utah	3	--	2	--	1	--
Nev.	1	--	1	--	1	--
Wash.	2	--	3	--	3	--
Cal.	10	--	12	--	12	--
Cont. U.S.	166	67	175	36	169	30

TABLE 6

AGE DISTRIBUTION OF U.S. SULFURIC ACID PLANTS, OPERATING IN 1965, HAVING AN ANNUAL CAPACITY OF 100,000 ST

- Capacities are shown in 1000 ST/yr.
- Two plants with unknown start up dates are included with those starting up in 1937 or earlier.

Start up or Latest Expansion	1937 or Earlier	1941	1942	1945	1946	1950	1952	1953
	109	106	109	105	100	136	363	136
	113	113	127	113	109	(1)	(1)	(1)
	127	118	136	136	122			
	154	132	254	159	236			
	159	145	295	272	318			
	159	159	295	817	(5)			
	179	181	318	(6)				
	181	218	454					
	190	229	476					
	200	250	(9)					
	204	762						
	272	(11)						
	363							
	(13)							

1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1965
109	181	109	190	136	127	127	499	191	476	127
113	250	127	295	159	159	318	(1)	227	(1)	136
136	726	136	454	191	272	476		363		349
(3)	(3)	159	(3)	(3)	(3)	(3)		(3)		381
		163								444
		(5)								(5)

- Total number of plants (counting multi-train plants as one): 80

TABLE 7

CAPACITY DISTRIBUTION OF PLANTS IN TABLE 6

Start Up Date or Latest Expansion	Capacity 1000 ST/Yr	% of Capacity	Cumulative % of Capacity
1937 or Earlier	2410	12.9	12.9
1941	2413	12.9	25.8
1942	2464	13.2	39.0
1945	1602	8.6	47.6
1946	885	4.7	52.3
1950	136	0.7	53.0
1952	263	1.9	54.9
1953	136	0.7	55.6
1954	358	1.9	57.5
1955	1157	6.2	63.7
1956	694	3.7	67.4
1957	939	5.0	72.4
1958	486	2.6	75.0
1959	558	3.0	78.0
1960	921	4.9	82.9
1961	499	2.7	85.6
1962	781	4.2	89.8
1963	476	2.5	92.3
1965	1437	7.7	100.0
	18715	100.0	

TABLE 8

LISTING OF U.S. SULFURIC ACID PLANTS, OPERATING IN 1965, HAVING ANNUAL CAPACITY OF 100,000 ST, LOCATED IN STATES WHERE CONSUMPTION OF COAL BY ELECTRIC UTILITIES IS SIGNIFICANT

Start Up Date or Latest Expansion	Capacity 1000 ST/Yr	State	Source of Sulfur						
			S Only	SM*	SM+S	SA*	SA+S	H_2S	H_2S+S
1937 or Earlier	113	Va.	X						
	154	Mich.	X(1)						
	159	Ky.	X						
	159	Pa.		X					
	179	N.J.	X						
	181	Ohio	X						
	190	Fla.	X						
	200	Pa.			X				
	204	Ga.	X						
	272	N.J.	X						
	363	Utah		X					
1941	113	Ohio	X						
	118	Ill.					X		
	132	Tenn.	X						
	145	Va.	X						
	181	N.Y.					X		
	218	Pa.					X		
	250	Ind.	X						
	762	Tenn.		X					
1942	127	Mass.	X						
	136	Fla.	X						
	253	Ill.	X						
	295	Del.				X			
	295	Ind.	X						
	318	Ill.	X						
	454	N.J.	X						
	476	Mo.			X				

TABLE 8 (cont'd)

Start Up Date or Latest Expansion	Capacity 1000 ST/Yr	State	Source of Sulfur S Only	SM*	SM+S	SA*	SA+S	H_2S	H_2S+S
1945	105	Ill.			X				
↓	113	Fla.	X						
	272	Del.	X						
	817	Fla.	X						
1946	109	Mont.		X					
↓	122	W.Va.	X						
	318	Md.	X						
1950	136	Ala.	X						
1953	136	Nev.	X?	?					
1955	181	Mich.					X		
1956	109	Ind.	X						
↓	127	Ill.	X						
	136	N.J.	X						
	159	Ohio	X						
	163	Ill.					X		
1957	190	Ala.							X
↓	454	Fla.	X						
1958	136	N.M.	X						
↓	191	N.J.					X		
1959	127	Minn.	X						
↓	159	Fla.	X						
	272	N.J.	X						
1960	476	Fla.	X						
1961	499	Fla.	X						
1962	191	Ill.	X(1)						
↓	363	Fla.	X						
1963	476	Fla.	X						
1965	136	Va.	X						
↓	381	Fla.	X(1)						

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(1) Elemental sulfur may be available from acid plant owner's captive production.

* S = Elemental Sulfur; SM = Smelter Gaes; SA = Spent Acid.

TABLE 9

CAPACITY SUMMARY FOR SULFURIC ACID PLANTS LISTED IN TABLE 8

Start Up Date or Latest Expansion	Number of Plants	Capacity in 1000 ST/Yr							
		Total	S Only	SM	SM+S	SA	SA+S	H_2S	H_2S+S
1937 or Earlier	11	2174	1452	522	200	--	--	--	--
1941	8	1919	640	762	--	--	517	--	--
1942	8	2355	1584	--	476	295	--	--	--
1945	4	1307	1202	--	105	--	--	--	--
1946	3	549	440	109	--	--	--	--	--
1950	1	136	136	--	--	--	--	--	--
1953	1	136	136	--	--	--	--	--	--
1955	1	181	--	--	--	--	181	--	--
1956	5	694	531	--	--	--	163	--	--
1957	2	644	454	--	--	--	--	--	190
1958	2	327	136	--	--	--	191	--	--
1959	3	558	558	--	--	--	--	--	--
1960	1	476	476	--	--	--	--	--	--
1961	1	499	499	--	--	--	--	--	--
1962	2	554	554	--	--	--	--	--	--
1963	1	476	476	--	--	--	--	--	--
1965	2	517	517	--	--	--	--	--	--
TOTAL	56	13502	9791	1393	781	295	1052	--	190
% of Capacity		100	72.5	10.3	5.8	2.2	7.8	--	1.4

TABLE 10

LISTING OF U.S. SULFURIC ACID PLANTS, OPERATING IN 1965, HAVING ANNUAL CAPACITY OF 100,000 ST, LOCATED IN STATES WHERE CONSUMPTION OF COAL BY ELECTRIC UTILITIES IS INSIGNIFICANT

Start Up Date or Latest Expansion	Capacity 1000 ST/Yr	State	Source of Sulfur						
			S Only	SM*	SM+S	SA*	SA+S	H_2S	H_2S+S
1937 or Earlier	109	Cal.					X		
"	127	Tex.					X		
1941	106	Okla.	X						
"	159	Cal.					X		X
"	229	Tex.	X						
1942	109	Tex.	X						
1945	136	La.							X
"	159	Cal.	X						
1946	100	Ark.	X						
"	236	Tex.	X						
1952	363	La.					X		
1954	109	Ida					X		
"	113	Cal.					X		X
"	136	Kan.				X			
1955	250	Tex.					X		
"	726	Tex.					X		
1957	295	Cal.					X		X
1958	159	Tex.					X		
1960	127	Cal.	X						
"	318	Tex.					X		
1962	227	Miss.	X						
1965	127	Cal.	X						
"	349	Ida.	X						
"	444	La.	X						
	5213								

* S = Elemental Sulfur; SM = Smelter Gases; SA = Spent Acid.

TABLE 11

CANDIDATE LIST OF ACID MANUFACTURERS THAT MIGHT CONSIDER OFFTAKING ABATEMENT ACID

Acid Manufacturer	Start Up Date	State and Acid Plant Capacity (1000 ST/YR)													
		Minn.	Ill.	Ind.	Ohio	Mass.	N.J.	Del.	Md.	W.Va.	Va.	Ga.	Fla.	Ky.	Ala.
Allied Chemical	(1)										113				
	1941				113						145				
	1946									122					
	1965										136				
Du Pont	(1)				181		272							159	
	1942			245											
	1956				159										
Am. Cyanamid	1970						224								
	1961												499		
	-											204			
Swift	-												190		
	1945												113		
	1959												159		
Grace (2)	1945							272							
	1960												476		
Monsanto (3)	1942		254												
	1969					100									
Olin (4)	1942		318												
	1946								318						
	-						224								
Stauffer	1941			250											
	1956			109											
U.S.S. Agrichem	1942												136		
	1962												363		
I.M.C.	1957												454		
Nat. Distillers	1956		127												
Nat. Lead	1942						454								

TABLE 11 (cont'd)

Acid Manufacturer	Start Up Date	State and Acid Plant Capacity (1000 ST/YR)													
		Minn.	Ill.	Ind.	Ohio	Mass.	N.J.	Del.	Md.	W.Va.	Va.	Ga.	Fla.	Ky.	Ala.
Cities Service	1945												817		
	1950														136
	1968											120			
Acid Inc.	1963												476		
Essex Chemical (5)	1956						136								
Dixon Chemical	1959						272								
North Star Chemical	1959	127													
State Totals	-	127	699	654	453	100	1582	272	318	122	394	324	3683	159	136

(1) 1937 or earlier

(2) Grace was the acid plant operator for the group of companies that tested Wellman-Lord's K Alkali System at Baltimore Gas and Electric

(3) Monsanto offers The "Cat-Ox" System of acid manufacture from stack gases. System has been piloted by Metropolitan Edison at Portland, Pa. and will be tested by Illinois Power at Wood River

(4) Olin is using Wellman-Lord's Na Alkali System on its acid plant at Paulsboro, N. J.

(5) Essex Chemical is believed to be intending to roast magnesium sulfite to produce SO_2 feed to its Rhode Island acid plant. The sulfite will come from Boston Edison's application of Chemico's stack gas treatment process

Note: Other than the interest evident from (2) - (5), there is no positive indication that the above acid manufacturers would be interested in offtaking abatement acid. However, these companies probably include the best prospects available

TABLE 12

MEGAWATT EQUIVALENT OF ACID PLANT CAPACITY LISTED IN TABLE 11

State	Acid Plant Capacity 1000 ST/Yr	Megawatt Equiv. (1)	Actual MW (2)	Ratio of (2) to (1)
Minn.	127	720	3,300	4.6
Ill.	699	4,000	15,500	3.9
Ind.	654	3,700	10,400	2.8
Ohio	453	2,600	16,200	6.2
Mass.	100	570	5,400	7.5
N.J.	1,582	9,000	7,200	0.8
Del.	272	1,550	890	0.6
Md.	318	1,800	3,900	2.2
W.Va.	122	700	6,400	9.1
Va.	394	2,250	5,100	2.3
Ga.	324	1.850	5,200	2.8
Fla.	3,683	21,000	12,300	0.6
Ky.	159	900	8,400	9.3
Ala.	136	780	7,100	9.1

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(1) Based on 60% load factor and 3 wt. % S coal.

(2) Actual steam electric generating capacity in December 1970 (including nuclear plants).

TABLE 13

ANNOUNCED CHANGES TO U.S. SULFURIC ACID CAPACITY SINCE 1967

Date	Company	State	Location	T/D	Remarks
1967	N.J. Zinc	Pa.	Palmerton	1200	Nearing completion. SO_2 ex roaster.
1967	Missouri Lead Smelting	Mo.	Salem	20	Smelter cases.
1967	Texas Gulf Sulphur	N.C.	Lee Creek	3050	Started up in 1966. Elemental S.
1967	Kennecott	Ariz.	Hayden	750	Smelter gases.
1967	Tennessee Copper (Cities Service)	Ga.	Augusta	375	
1967	Stauffer Chemical	Texas	Houston	2000	May operate at 2700 T/D.
1967	Pfizer	Pa.	Easton	N.A.	
1968	Olin	N.J.	Paulsboro	(900)	Purchased from Paulsboro Chem. Ind.
1968	DuPont	Mich.	Ecorse	(480)	Sold to National Steel.
1968	Kent Feeds	Iowa	Muscatine	Small	Experimental process.
1968	Stauffer Chemical	Cal.	San Francisco	500-1000	Designed to run on Shasta Co. pyrites.
1968	Monsanto	Mass.	Everett	300	Startup mid-1969. To replace old unit.
1968	St. Joseph Lead	Pa.	Josephtown	250	
1968	St. Joseph Lead	Mo.	Herculaneum	300	Planning. Lead smelter gases.
1968	National Zinc	Okla.	Bartlesville	275	
1968	Freeport	La.	Uncle Sam	4800	Elemental S.
1969	Am. Cyanamid	N.J.	Linden	700	Startup in 1970. Elemental S.
1969	Amoco (Indiana Standard)	Texas	Texas City	495	Acid used for alkylation.
1969	U.S.I. Chemical (Nat Distillers)	Kan.	De Soto	300	Expansion to 300 T/D.
1969	Kennecott	Utah	Magna	375-625	Copper smelter gases.
1969	National Lead	Mo.	St. Louis	900	Replacing old plants. Acid use: Pb pigments.
1969	Tennessee Corp. (Cities Service)	Tenn.	Copperhill	600	25% expansion. Fe, Cu, Zn smelting.
1969	Bunker Hill	Idaho	Kellogg	300	Lead sinter operation.
1970	Asarco	Ariz.	Hayden	750	Smelter cases.
1970	Am. Cyanamid	N.J.	Linden	-450	Old plants shut down*
1970	Olin	La.	Shreveport	400	Will close old 200 T/D plant.
1970	Olin	Texas	Pasadena	1250	Mid-1971 startup.
1970	Farmland Industries	Fla.	Bartow	?	"Two large units." 1971 startup.
1971	Cities Service	N.J.	Monmouth Jct.	100	Mid-1971 startup. Iron oxide plant.
1971	Coastal Chemical	Miss.	Pascagoula	1500	Late 1971 startup.
1971	Kennecott	Utah	Magna	500	Boosts smelter's total acid production to 1300 T/D.

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* Unable to meet state air pollution control regulations.

TABLE 14

SUMMARY OF CAPACITY ADDITIONS BY STATE

State	Year	Addition 1000 ST/Yr
Pa.	1967	384
	1967	?
	1968	80
		464+
Mass.	1968	96(1)
N.J.	1970	224(2)
	1971	32
		256
N.C.	1966	976
Ga.	1967	120
Fla.	1971	?
Mo.	1967	6
	1969	288(3)
	?	96
		390
Tenn.	1969	190

State	Year	Addition 1000 ST/Yr
Kan.	1969	96
Okla.	1968	88
Miss.	1971	480
La.	1968	1536
	1970	128
		1664
Tex.	1967	860
	1971	400
		1260
Ida.	1969	96
Utah	1969	200
	1971	200
		400
Ariz.	1967	240
	1970	240
		480
Calif.	1968	320

---

(1) Replacing 127,000 ST/Yr. plants.
(2) Replacing 144,000 ST/Yr. plants.
(3) Replacing 476,000 ST/Yr. plants.

TABLE 15

GEOGRAPHICAL PATTERN OF RECENTLY ADDED SULFURIC ACID CAPACITY

State	% of New Capacity	(1)	(2)	State	% of New Capacity	(1)	(2)
Mass.	1.3	0.6	0.8	Kan.	1.3	0.9	1.1
N.J.	3.4	7.5	9.2				
Pa.	7.5	4.0	4.8	Miss.	6.4	1.0	1.2
				La.	22.3	4.7	5.7
N.C.	13.1	0.9	1.1	Texas	16.9	9.7	11.8
Ga.	1.6	2.0	2.4				
Fla.	N.A.	17.7	--	Idaho	1.3	1.9	2.3
				Utah	5.3	1.6	2.0
Mo.	5.2	2.3	2.7	Ariz.	6.4	1.0	1.2
Tenn.	2.5	3.9	4.7				
				Cal.	4.3	5.2	6.4

---

(1) State's percentage of U.S. capacity at end of 1965.

(2) State's percentage of U.S. capacity excluding Florida (to make more comparable with recent capacity additions that also exclude Florida).

TABLE 16

NEW SULFURIC ACID PRODUCTION IN THE U. S.

	1000 ST of Sulfuric Acid					
	1964	1965	1966	1967	1968	1969
Pennsylvania	941	972	966	876	916	909
New Jersey	1826	1736	1755	1627	1522	1341
Me, Mass, RI, NY	193*	207*	202*	190*	327	302
Ohio	675	704	689	653	629	578
Illinois	1697	1704	1765	1834	1725	1553
Michigan	347	323	342	306	247	193
Ind, Wis, Minn, Ia, Mo, Kan	1598	1623	1681	1612	1546	1756
Del, Md	1043	1035	1049	938	979	852
Virginia	518	526	630	604	654	654
N. Carolina	156	159	217	721	872	859
S. Carolina	168	164	159	152	125	115
Georgia	443	512	559	555	589	592
Florida	4405	5558	7490	8126	7372	7182
Alabama	437	456	415	399	408	389
Louisiana	763	807	1303	1172	1855	2297
Texas	2274	2502	2943	2718	2539	2479
W Va, Ky, Miss, Tenn, Ark, Okla,	1909	1955	1892	1932	1837	1998
Arizona	197	177	227	168	207	308
California	1163	1398	1423	1547	1485	1393
Mont, Ida, Utah, Cal, Wyo Nev, NM, Wash, Haw	1206	1292	1706	1607	1583	1688
TOTAL	21959	23813	27414	27736	27417	27439

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* NY included with NJ until 1968.

TABLE 17

TRENDS IN U. S. SULFURIC ACID PRODUCTION

		% of Total U.S. Production						Δ %
		1964	1965	1966	1967	1968	1969	1969/1964
(1)	Florida	20.0	23.2	27.5	29.3	26.7	26.2	+6.2
(2)	Louisiana	3.5	3.4	4.8	4.2	6.8	8.4	+4.9
(3)	Texas	10.4	10.5	10.7	9.8	9.2	9.0	-1.4
(4)	Ala, Miss, Okla, Tenn, Ark, Ky, W. Va.	10.6	10.1	8.4	8.4	8.2	8.7	-1.9
(5)	Ariz, N.M, Nev, Utah, Col, Wyo, Mont, Ida, Wash, Hawaii	6.4	6.1	7.0	6.4	6.6	7.2	+0.8
(6)	California	5.3	5.9	5.2	5.6	5.4	5.1	-0.2
(7)	Ind, Wis, Minn, Iowa, Mo, Kan	7.3	6.8	6.1	5.8	5.6	6.4	-0.9
(8)	Illinois	7.7	7.2	6.4	6.6	6.3	5.7	-2.0
(9)	Ohio, Michigan	4.7	4.4	3.7	3.5	3.2	2.8	-1.9
(10)	Pa, NJ, NY, Mass, Me, RI	13.5	12.3	10.7	9.8	10.0	9.3	-4.2
(11)	Del, Md, Va, N.C., S.C., Ga	10.6	10.1	9.5	10.7	11.8	11.2	+0.6
TOTAL		100	100	100	100	100	100	---

TABLE 18

RELATIVE ECONOMICS OF RECOVERING ABATEMENT SULFUR IN DIFFERENT FORMS

- Assumptions

E = delivered cost of elemental S, in \$ per LT, to prospective purchasers of abatement S from an existing sulfur supplier.
T = delivery cost for elemental S, in \$ per LT, from the abatement plant to prospective purchasers. (Hence, 4T would be the approximate delivery cost for 100% sulfuric acid, in \$ per LT of S equivalent, from the abatement plant to prospective purchasers.)
X = cost of recovering S in elemental form, in \$ per LT.
Y = cost of recovering S as sulfuric acid, in \$ per LT of S equivalent.
Z = cost of recovering S as throwaway product, in \$ per LT of S equivalent.
M_1 = marketing cost for recovered elemental S, in \$ per LT.
M_2 = marketing cost for recovered acid, in \$ per LT of S equivalent.
M_3 = disposal cost for throwaway product, in \$ per LT of S equivalent.

- Best Choice

(1) Elemental Sulfur:
if $(E-T-X-M_1)$ is greater than $(E+15-4T-Y-M_2)$, and also greater than $-(Z+M_3)$.

(2) Sulfuric Acid:
if $(E+15-4T-Y-M_2)$ is greater than $(E-T-X-M_1)$, and also greater than $-(Z+M_3)$.

(3) Throwaway Product:
if $-(Z+M_3)$ is less negative than $(E-T-X-M_1)$, and also less negative than $(E+15-4T-Y-M_2)$.

Notes: The above relationships are approximate only and do not take account of marketing and other special factors that may apply to individual situations. Furthermore, the possibility that the situation may change with time should be considered. Users of the relationships are advised to heed these qualifications.

TABLE 19

HISTORICAL MOVEMENTS IN THE U. S. PRICES OF ELEMENTAL SULFUR AND SULFURIC ACID

Year	(A) Approx. Delivered Price of El. S Gulf Coast, $/LT	(B) Cost of 0.307 LT Of S*	(C) List Price Per ST of 100% H_2SO_4	(D) Acid Price -S Cost $/ST	(E) GNP Deflator	(D) x (E) Differential In Constant Dollars/ST
1952	25.0	7.67	21.3	13.6	1.144	15.6
3	27.3	8.38	23.8	15.4	1.132	17.4
4	30.5	9.36	23.8	14.4	1.116	16.1
5	30.5	9.36	23.8	14.4	1.101	15.9
6	30.5	9.36	23.8	14.4	1.064	15.3
7	29.0	8.90	23.8	14.9	1.026	15.3
8	27.50	8.44	23.8	15.4	1	15.4
9	27.50	8.44	23.8	15.4	0.9839	15.2
1960	27.50	8.44	23.8	15.4	0.9862	15.2
1	27.50	8.44	23.8	15.4	0.9560	14.7
2	27.50	8.44	23.8	15.4	0.9456	14.6
3	27.50	8.44	23.8	15.4	0.9331	14.4
4	28.50	8.75	23.8	15.0	0.9189	13.8
5	30.50	9.36	25.3	15.9	0.9020	14.3
6	30.75	9.44	26.9	17.5	0.8776	15.4

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*Required to produce 1 ST of 100% H_2SO_4

Notes: 1. Acid price is "ex works"
2. Prices quoted are "list" not actual transfer prices

TABLE 20

RECENT MOVEMENTS IN U. S. PRICES OF ELEMENTAL SULFUR AND SULFURIC ACID

Date	(A) Approx. Del. Price of S Gulf Coast, $/LT	(B) $ Cost of 0.307 LT Of S	(C) $/ST List Price of 100% H_2SO_4	(D) Acid Price -S Cost $/ST	(E) GNP Deflator	(D) x (E) Differential in Constant $/ST
1967	28.25	11.74	30.5	18.8	0.8502	16.0
1968	46.00	14.12	34.6	20.5	0.8174	16.8
1969	39.50	12.13	34.7	22.6	0.7807	17.6
1970	25.50	7.83	30.8	23.0	0.7414	17.1
May 1971	23.00*	7.06	30.8	23.7	0.7325*	17.4

* Estimated

- Further detail of sulfuric acid prices, ($/ST of 100% acid):

Date	ex Works*	ex Calif. Works	Gulf Coast	E. Coast	W. Coast	Other*
1/2/67	27.65	29.55	--	--	--	--
4/24/67	29.15	31.05	--	--	--	--
8/7/67	30.40	32.30	--	--	--	--
			**	**	**	**
12/28/70	--	--	30.75	33.75	35.80	33.90
5/3/71	--	--	30.75	33.75	35.80	33.90

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* Location not specified.

** Reported as "low" prices. "High" quotes are $2/ST higher.

TABLE 21

RECAPITULATION OF MOVEMENTS IN U. S. PRICES OF ELEMENTAL SULFUR AND SULFURIC ACID

Date	Approx Del. Price of Sulfur in Current $/LT	List Price of 100% Acid Current $/ST	(D) Differential (Acid-S) Constant $/ST	Construction Cost Index Normalized By GNP Deflater
1952	25.0	21.3	15.6	87.7
1955	30.5	23.8	15.9	95.6
1960	27.5	23.8	15.2	106.9
1965	30.5	25.3	14.3	115.2
1967	38.3	30.5	16.0	119.7
1968	46.0	34.6	16.8	124.2
1969	39.5	34.7	17.6	130.5
1970	25.5	34.7*	19.9	134.6
May 1971	23.0	34.7*	20.2	142.0 (Mar 71)

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* See text of report for assumption that acid prices have not decreased since 1969.

TABLE 22

COMPARISON OF VALUE PER ST OF 100% H_2SO_4 REPORTED BY DEPT. OF COMMERCE WITH EX WORKS LIST PRICE (REPORTED BY OIL, PAINT, AND DRUG REPORTER)

	U.S. Dept. of Commerce $/ST of 100% Acid			
	Total Shipments Including Interplant Transfers	Commercial Shipments Only	O.P.D.R. List Price $/ST	Differential (B)-(A) $/ST
Total U.S.		(A)	(B)	
1964	16.7	16.6	23.8	7.2
1965	16.8	16.6	25.3	8.7
1966	17.4	17.3	26.9	9.6
1967	18.7	18.6	30.5	11.9
1968	21.3	21.3	34.6	13.3
N.Y., N.J.	(C)			(B)-(C)
1967	23.6	--		6.9
1968	27.3	--		7.3

Note: Above data in conjunction with Table 21 suggest that the O.P.D.R. list price for 100% H_2SO_4 is a reasonable reflector of price trends but overstates actual average sales price of acid by at least $7/ST.

- Comparison of O.P.D.R. list price with Nelson's Petroleum Refining OperatingCost Index for sulfuric acid (1965=100)*

	O.P.D.R. $/ST	O.P.D.R. as Ratio of 1965	Nelson Index
1965	25.3	100	100
1967	30.5	120.6	125.7
1968	34.6	136.8	143.2
1969	34.7	137.2	144.5
1970	34.7	137.2	144.5

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*As reported periodically in the Oil and Gas Journal.

TABLE 23

AVERAGE PRODUCTION OF SULFURIC ACID PER PLANT IN 1968

	Average Production ST/CD
New Jersey	463
Pennsylvania	251
Delaware & Maryland	384
Virginia	163
South Carolina	49
Georgia	115
Florida	1188
Ohio	172
Illinois	315
Michigan	135
Arizona	142
California	339
U.S.	356

Based on Department of Commerce data.

TABLE 24

U. S. SULFURIC ACID SHIPMENTS* AND VALUES OF SHIPMENTS IN 1967 AND 1968

	1967		1968	
	10^6 ST	$/ST*	10^6 ST	$/ST**
New England	0.11	27.7	0.11	33.2
Middle Atlantic				
N.Y., N.J.	0.85	23.6	0.86	27.3
Pa.	0.81	20.1	0.85	23.0
South				
Del., Md.	0.61	22.2	0.68	24.9
Va.	0.40	21.2	0.47	24.7
S.C.	0.05	20.2	0.04	19.4
Ga.	0.13	21.7	0.26	21.7
Fla.	1.26	14.3	0.60	15.9
La.	0.61	17.9	0.79	21.0
Tex., Okla.	2.61	15.0	2.15	18.0
Other	1.63	19.4	1.67	20.8
N. Central				
Ill.	0.79	19.3	0.81	20.6
Mich.	0.28	23.7	0.22	28.2
Ohio	0.52	24.8	0.52	28.0
Other	1.02	21.4	0.87	24.0
West				
Ariz.	0.09	15.3	0.09	16.2
Calif.	1.01	18.3	1.00	19.8
Other	0.74	15.1	0.84	15.5
Total U.S.	13.50	18.7	12.83	21.3

* Excludes captive consumption in plants producing acid.

** As reported to U. S. Dept. of Commerce, inclusive of interplant transfers.

TABLE 25

ESTIMATES OF CAPTIVE CONSUMPTION OF SULFURIC ACID IN REPRESENTATIVE STATES (1968)

	Thousand ST of 100% Acid			
	(A) Production of New Acid	(B) Shipments + Interplant Transfers	(A-B) Apparent Captive Consumption	(A-B) as % of (A) % Captive Consumption
Pennsylvania	916	851	65	7
N.Y., N.J. (1967)	1628	862	766	47
Del., Md.	979	675	304	31
Virginia	654	470	184	28
S. Carolina	125	39	86	69
Georgia	589	263	326	55
Florida	7372	597	6775	92
Louisiana	1855	790	1065	57
Illinois	1725	813	912	53
Michigan	247	219	28	11
Ohio	629	520	109	17
Arizona	207	94	113	55
California	1485	1002	483	33
Total U.S.	27417	12832	14585	53
U.S. ex Florida	20045	12235	7810	39

Source: U. S. Dept. of Commerce

TABLE 26

U. S. CAPACITY FOR PRODUCING P_2O_5 IN 1967 AND PROJECTIONS FOR FY 1976

	Total U.S.	298 Metropolitan Areas
Number of Plants (1967)	179	147
Capacity, 10^6 ST of P_2O_5	12.2	10.3
Production, 10^6 ST of P_2O_5	7.0	5.7
Capacity Utilization, %	57	55
Value of Shipments, $ MMM	1.6	1.2
• Projections for FY 1976		
Capacity, 10^6 ST of P_2O_5	--	15.6
Production, 10^6 ST of P_2O_5	--	8.5
Capacity Utilization, %	--	54
Value of Shipments, $ MMM	--	1.8

Source: Tables 4-4 and 4-7 of Senate Document No. 92-6.

TABLE 27

U. S. CAPACITY FOR PRODUCING ELEMENTAL PHOSPHORUS IN 1967

	Total U.S.	298 Metropolitan Areas
Number of Plants	13	8
Capacity, 1000 ST	658	290
Production, 1000 ST	587	279
Capacity Utilization, %	89	96
Value of Shipments, $ MM	200*	140*

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* These figures in relation to the quantities produced suggest that much of the production was used captively, i.e., was not "shipped" as elemental P.

Source: Table 4-8 of Senate Document No. 92-6.

TABLE 28

U. S. CAPACITY FOR PRODUCING PHOSPHATE FERTILIZERS IN 1967

	Total U.S.	298 Metropolitan Areas
Number of Plants	179	147
Capacity		
• Ortho Acid, 1000 ST of P_2O_5	5860	4830
• Super Acid, 1000 ST of P_2O_5	316	149
	6176	4979
• NSP, Gross Wt., 1000 ST	4690	3840
• AP, Gross Wt., 1000 ST	7430	6430
• TSP, Gross Wt., 1000 ST	3640	3460
Production		
• Fertilizer, 1000 ST	4700	4100
• P Acid, 1000 ST	5190	4200

Source: Table 4-9 of Senate Document No. 92-6.

TABLE 29

WET PROCESS PHOSPHORIC ACID CAPACITY IN 1967

State	Location(1)	Company(2)	Annual (3)	Capacity (4)	Start-Up	Captive H_2SO_4
Fla.	Bartow	Farmland Ind. (5)	181	580	1965	Yes
	Bartow	Grace	254	810	1954, 1961	Yes
	Bartow	Swift	82	260	1949, 1961	Yes
	Bartow	Armour (6)	60	190	1964	Yes
	Ft. Meade	Armour	150	480	1960	Yes
	Pierce	Agrico (7)	195	620	1965	Yes
	Brewster	Am. Cyanamid	196	630	1957, 1962	Yes
	Bonnie	IMC	420	1340	1962, 1965	Yes
	Nichols	Mobil (8)	145	460	--	Yes
	Mulberry	Royster Guano	27(9)	90	1953	Yes
	Plant City	Central Phosphates	150	480	1966	No
	Piney Pt.	Borden Chem. (10)	127	400	--	Yes
	E. Tampa	Tennessee Corp. (11)	400	1280	1965	Yes
	White Springs	Occidental	204	650	1966	?
	Pensacola	Escambia Chem.	26	80	--	No
La.	Uncle Sam	Freeport	544	1740	1968	Yes
	Geismar	Allied Chem.	150	480	1967	Yes
	Taft	Hooker (Occidental)	191	610	1965	Yes
Tex.	Texas City	Borden (10)	36	110	--	Yes
	Pasadena	Olin	180	580	1964, 1965	Yes
	Pasadena	Phillips/Stauffer	45	140	1965	Yes
	Adams Terminal	Phillips	90	290	--	?
N.C.	Lee Creek	TGS	314	1000	1966	Yes
Miss.	Pascagoula	Coastal Chem.	165	530	1959, 1965	Yes
Pa.	Marcus Hook	Allied Chem.	30	100	--	Yes
Del.	Claymont	Allied Chem.	30	100	1930	Yes
Minn.	Pine Bend	N.W. Co-Op. Mills	33	110	1962	No

TABLE 29 (con't)

State	Location(1)	Company(2)	Annual (3)	Capacity (4)	Start-Up	Captive H_2SO_4
Ill.	E. St. Louis	Allied Chem.	20	60	1961	Yes
	Streator	Borden Chem. (10)	30	100	1953	Yes
	Morris	Des Plaines Chem.	45	140	1963	No
	Marseilles	Hooker (Occidental)	91	290	1962	Yes
	Tuscola	Nat. Distillers	27	90	1957	Yes
	Joliet	Olin	113	360	1961	Yes
	Depue	N.J. Zinc	117	370	1966	Yes
Mo.	Joplin	Farmers Chem. (5)	45	140	1954, 1962	No
	Joplin	Grace	30	100	1955	Yes
Ark.	Helena	Arkla Chem.	45	140	1965	No
Okla.	Tulsa	Nipak	27	90	1957	Yes
Ida.	Kellogg	Bunker Hill	33	110	1961	Yes
	Pocatello	Simplot	197	600	1961, 1966	Yes
	Soda Springs	El Paso N.G.	91	290	1965	Yes
Utah	Garfield	Stauffer	45	140	1954	Yes
Cal.	Edison	A.F.C. Inc.	10	30	--	Yes
	Trona	Ampot (12)	3	10	--	No
	Lathrop	Best (Occidental)	30	100	1954	Yes
	Helm	Valley Nitrogen	49	160	1965	Yes
	Nichols	Western States Chem.	17	50	1959	No

---

(1)
- Bartow, Ft. Meade, Pierce, Brewster, Bonnie, Nichols and Mulberry are in essentially the same location.
- E. Tampa and Piney Pt. are in essentially the same location.
- Plant City is close to, and in between, the above groups of Florida cities.
- Uncle Sam, Geismar and Taft are in essentially the same location in Louisiana.
- Texas City, Pasadena and Adams Terminal are in essentially the same location in Texas.

TABLE 29 (cont'd)

(2) In some cases the companies listed are affiliates of other companies or have changed ownership since 1967, as detailed in separate footnotes below.

(3) 1000 Metric tons/year of phosphoric acid expressed as P_2O_5.

(4) 1000 ST/year of sulfuric acid capacity equivalent to (3), basis: 3.2 ST 100% Sulfuric acid equivalent to 1 MT of P_2O_5.

(5) Affiliates of Consumers Co-Op.

(6) Now a part of U.S.S. Agrichem.

(7) Conoco.

(8) Fertilizer operations believed to have been sold to Swift.

(9) Later expanded to 174,000 MT/year.

(10) Represents acquisition of Smith-Douglas fertilizer operations.

(11) Cities Service.

(12) Kerr McGee.

Note: Freeport's Uncle Sam, La., plant is included in tabulation even though it did not begin operations until 1968.

Sources: British Sulphur Corporation
Battelle Memorial Institute

TABLE 30

PHOSPHORIC ACID CAPACITY BY STATE

State	1000 MT/Yr. of P_2O_5	% of U.S. Capacity	Capacity Expressed as 1000 ST/Yr. H_2SO_4*	Imputed H_2SO_4 Capacity as % of Total U.S. Capacity
Florida	2617	47.9	8370	21.6
Louisiana	885	16.1	2830**	7.3
Texas	351	6.4	1120	2.9
Mississippi	165	3.0	530	1.4
N. Carolina	314	5.7	1000	2.6
Pennsylvania	30	0.5	100	0.3
Delaware	30	0.5	100	0.3
Minnesota	33	0.6	110	0.3
Illinois	443	8.1	1420	3.7
Missouri	75	1.4	240	0.6
Arkansas	45	0.8	140	0.4
Oklahoma	27	0.5	90	0.2
Idaho	311	5.7	1000	2.6
Utah	45	0.8	140	0.4
California	109	2.0	350	0.9
	5480	100.0	17540	45.5

---

* Based on 3.2 ST of sulfuric acid per MT or P_2O_5.

** Including Freeport's Uncle Sam plant that started up in 1968.

Notes: (1) 88% of the above capacity uses captively produced sulfuric acid. 6.6% of the above capacity uses purchased sulfuric acid. In the case of 2 plants, 5.4% of above capacity, it is not known whether the sulfuric acid is purchased or captive.

(2) Almost all of the above P acid capacity is used for fertilizers.

(3) Additional sulfuric acid capacity, not included above, is used to make ammonium sulfate and NSP fertilizers, i.e., total H_2SO_4 capacity for fertilizers exceeds 45.5% of total acid capacity.

Sources: Table 29, and also Table 4-4 of Senate Document No. 92-6, 3/16/71.

APPENDIX 1

BASIS OF LONG RANGE FORECASTS

A.1.1 Selection of Economic Forecasts

Historical economic data and projections of economic growth are available for all industrialized countries. The latter, of course, account for almost all of the world's industrial production. In turn, the latter is responsible for almost all of the industrial demand for sulfur. In consequence, projections of economic growth can be converted into forecasts of industrial demand for sulfur via suitable correlations. There are two principal problems associated with such projections:

- how to select among different forecasts that, almost always, are based on optimistic long range assumptions.
- how to take account of technological changes that will affect consumption patterns.

There is virtually no consumer demand for sulfur, sulfuric acid, etc. Almost all of the sulfur consumed industrially is used for processing, usually in the form of "acid value" rather than for the purpose of incorporating sulfur into the product. Thus, the demand for sulfur is induced by the demand for the products that use it in their manufacture. Because these products are so diverse, the industrial demand for sulfur may be expected to correlate with general indicators of economic activity. In the U.S., a wide variety of economic indicators in maintained on a time series basis, and recorded in "Survey of Current Business" and other Department of Commerce publications.

An article in the April 1970 edition of "Monthly Labor Review" previewed economic projections made by personnel of the Bureau of Labor Statistics. The BLS forecast was chosen over a comparable study by the National Planning Association because of the inter-agency approach used and because its assumptions better reflect the significance of the economic downturn. Even the BLS forecast is considered too optimistic on a near term basis. This has been allowed for when extrapolating to the year 2020.

An O.E.C.D study, "The Outlook for Economic Growth,"* was used as the starting point for projections of foreign economic growth. Although this study contains projections for Japan, an actual Japanese source was selected as discussed below.

An econometric forecast prepared by the Japan Economic Research Center of Tokyo was chosen as the published basis for projecting long range economic growth in Japan. This study, too, is considered to be too optimistic in its assumptions of rate of export expansion. The latter, of course, has an impact on the level of industrial activity in Japan. Declining rates of Japanese economic expansion are considered probable. Nevertheless, the absolute pace at which the Japanese economy expands is expected to be rapid. While such economic growth will increase the industrial consumption of sulfur, an even more important consequence will follow from the combined effects of five other factors:

- rapidly increasing demand for industrial energy.
- substantial reliance on imported petroleum for industrial energy.
- high sulfur content of average crude oil imported.
- availability of technology for hydrodesulfurization of petroleum.
- air pollution regulations that will ensure that hydrodesulfurization is used.**

Thus, the net effect is expected to be a rapidly increasing export capability, with most of the incremental supplies being recovered from petroleum. However, recovery of sulfur from smelter gas will also contribute increasingly to net export capability.

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* Organization for Economic Cooperation and Development, May 1970.

** MITI makes this a condition for approval of additions to petroleum refining capacity.

A.1.2 Problems with Economic Forecasts

Economic forecasts vary from almost apocalyptic gloom to unbridled optimism. Most official forecasts make optimistic assumptions with respect to growth in GNP, full employment, and (until recently) no serious consequences of adverse B.O.P.

Several projections for U.S. GNP are reviewed in Table 1 (converted where necessary to a common 1958 constant dollar basis). RFF's "Medium" projection, that was published in 1963, is noteworthy because its forecast for 1970 was within 1.5% of actual performance. The same forecasts are repeated in Table 2 as a percentage of RFF's "Medium" projections. Naturally, the effect of different growth rate assumptions is most evident in later years. For example, if RFF's "High" projection were to be followed (which is extremely unlikely), it could be predicted that a sulfur surplus would continue almost indefinitely.

Table 3 reveals the problem posed by Japan. Within the next decade Japan will become a major exporter of sulfur. If the economic growth rates shown in Table 3 were to be sustained, Japan's export capability would be enormous.

The implications of continuation of the Japanese GNP growth rates are indicated in Table 4. The results are totally unbelievable. Simple intuition, or common sense, argues that the Japanese economy will not expand by a factor of 345 in the next 50 years - while the U.S. economy is growing six or seven fold. However, the JERC forecast from which these unbelievable numbers were extrapolated looks ahead only to 1975 - nothing is said about the year 2020. In fact it is a very useful forecast, but requires projection on a declining rate basis.

A.1.3 Economic Projections Used in Sulfur Model

Historical data for worldwide GNP, converted to 1958 constant dollars, are given in Table 5. The figures for 1970 are partially estimated. Comparable data for population are given in Table 6. These statistics, in conjunction with the forecasts discussed in Section A.1.1, formed the base from which projections were made to the year 2020.

Population projections are given in Table 7, with the growth rate implications in the right half of the table. The population distribution corresponding to these projections is shown in Table 8.

The next steps were to project constant dollar GNP and to calculate GNP/capita. The results are given in Table 9. The percentage distribution of GNP corresponding to these projections is shown in Table 10. For the purposes of the Sulfur Model, these economic projections are considered to be "most probable," i.e. to represent the economic base case. However, an alternative "low economic growth" case was also calculated. The results are given in Tables 11 and 12. The underlying growth rate implications, in terms of GNP/capita for each of the cases are shown in Table 13. The data are also presented in ratio form in Table 14. The greatest differences between the "most probable" and the "low economic growth" cases are for Japan, Asia (excl. Japan), and the Middle East countries. The ratios in Table 14 may be applied, separately, to the regional projections of sulfur supply and demand in Appendices 4 and 5 in order to derive approximations of the regional supply/demand balances that would be expected to exist under the "low economic growth" assumptions. This procedure is feasible for a single region, such as Japan, for groups of regions, or for the entire world.

APPENDIX I

TABLE 1

COMPARISON OF VARIOUS PROJECTIONS OF U.S. GNP

	BILLIONS OF CONSTANT 1958 DOLLARS					
	1970	1980	1990	2000	2010	2020
RFF "Low" Projection	702	952	1243	1654	2244*	3045*
Compound 3.0%/yr Growth	725	974	1309	1759	2364	3177
RFF "Medium" Projection	736	1049	1494	2169	3164*	4616*
Slowly Declining Growth Rate[ø]	725	1073	1573	2284	3284	4677
Bureau of Mines Long Range Energy Model	748	1122	1661	2460	3641*	5385*
Compound 4.2%/yr Growth	725	1094	1651	2491	3758	5671
1970 National Planning Association Study	--	1144	--	--	--	--
1970 BLS Study**	--	1157	--	--	--	--
RFF "High" Projection	787	1234	1953	3242	5181*	8280*

---

* Extrapolated

ø 1970/80 4.0%/yr, 1980/90 3.9%/yr, 1990/2000 3.8%/yr etc.

** "Services economy" with 4% unemployment

APPENDIX I

TABLE 2

COMPARISON OF U.S. GNP PROJECTIONS AS RATIOS OF RFF "MEDIUM" PROJECTION

	1980	1990	2000	2010	2020
RFF "Low" Projection	91	83	76	71	66
Compound 3.0%/yr Growth	93	88	81	75	69
RFF "Medium" Projection	100	100	100	100	100
Slowly Declining Growth Rate	102	105	105	104	101
B.O.M. Energy Model	107	111	113	115	117
Compound 4.2%/yr Growth	104	111	115	119	123
1970 NPA Study	109	--	--	--	--
1970 BLS Study	110	--	--	--	--
RFF "High" Projection	118	131	149	164	179

APPENDIX I

TABLE 3

COMPARISON OF VARIOUS JAPANESE ECONOMIC FORECASTS

Forecast made by	Date	Forecast Period	Compound Annual % Growth Projected for Real* GNP
Sanwa Bank	1969	1970-75	9.3
Nomura Research Inst.	1968	1967-73	10.3
Mitsubishi Economic Research Inst.	1969	1967-77	10.4
Japan Life Insurance Co.	1969	1968-75	10.5
Industrial Bank of Japan	1969	1969-75	11.2
Long-term Credit Bank of Japan	1969	1968-75	11.3
National Economic Research Assoc.	1969	1969-73	11.8
Japan Economic Research Center	1969	1970-75	12.4

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*Equivalent to constant dollars.

APPENDIX I

TABLE 4

IMPLICATIONS OF CONTINUATION OF GROWTH AT SAME RATE AS THAT USED IN CURRENT FORECAST

	Ratio of Japanese Real GNP in 2020 to GNP in 1970
Sanwa Bank	85
Nomura Research	135
Mitsubishi	141
Japan Life	147
Industrial Bank	202
Long-term Credit Bank	211
NERA	264
JERC	345*

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* This implies a Japanese GNP 345 times greater than the GNP today. This is equivalent to 71 times the size of the U.S. GNP today, or 11 times the size of the U.S. GNP in the year 2020 based on extrapolation of RFF's "Medium" projection.

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TABLE 5

CONSTANT DOLLAR GNP -- HISTORICAL DATA

	Billions of 1958 Constant Dollars				
	1950	1955	1960	1965	1970E
U.S.	355.3	438.0	487.7	617.8	723.5
Canada	27.5	33.0	35.2	43.4	58.7
Japan	15.8	26.2	43.5	76.4	146.1
European OECD	214.0	267.0	340.0	462.0	548.0
OECD	612.6	764.2	906.4	1199.6	1476.3
Latin America	52.8	60.3	69.0	87.0	105.6
Africa	21.4	25.7	34.0	43.7	57.0
Middle East	3.7	5.3	7.5	10.6	17.0
Far E (ex. Japan)	52.0	69.5	93.0	127.0	160.0
NON-OECD	129.9	160.8	203.5	268.3	339.6
Free World	742.5	925.0	1109.9	1467.9	1815.9
F.W. ex. U.S.	387.2	487.0	622.2	850.1	1092.4
Communist Bloc	116.0	206.0	313.0	429.0	551.5
World	858.5	1131.0	1422.9	1896.9	2367.4

Sources: U.N. Statistical Yearbook
U.S. Dept. of Commerce

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TABLE 6

HISTORICAL POPULATION DATA (MILLIONS)

	1950	1955	1960	1965	1970E
U. S.	152.3	165.9	180.7	194.6	205.4
Canada	13.7	15.7	17.9	19.6	21.5
Japan	82.9	89.0	93.2	98.0	103.4
European OECD	306.4	319.8	334.9	354.0	370.1
OECD	555.3	590.4	626.7	666.2	700.4
Latin America	161.7	184.8	212.7	245.0	282.6
Africa	219.0	247.0	278.7	313.3	355.5
Middle East	41.2	45.8	52.7	59.9	66.5
Far E. (ex. Japan)	660.6	714.7	820.1	930.8	1053.7
NON-OECD	1082.5	1192.3	1364.2	1549.0	1758.3
Free World	1637.8	1782.7	1990.9	2215.2	2458.7
F. W. ex.U. S.	1485.5	1616.8	1810.2	2020.6	2253.3
Communist Bloc	871.8	941.4	1008.8	1084.3	1156.1
World	2509.6	2724.1	2999.7	3299.5	3614.8

Sources: U. N. Demographic Yearbook
U. S. Dept. Of Commerce

APPENDIX 1

TABLE 7

POPULATION PROJECTIONS TO THE YEAR 2020

	Millions						Compound Growth % Per Year				
	1970	1980	1990	2000	2010	2020	70/80	80/90	90/00	00/10	10/20
U.S.	205.4	229.1	255.6	282.3	308.8	334.4	1.1	1.1	1.0	0.9	0.8
Canada	21.5	26.0	31.1	36.8	42.7	49.1	1.9	1.8	1.7	1.5	1.4
Japan	103.4	114.2	126.1	137.9	149.3	160.1	1.0	1.0	0.9	0.8	0.7
European OECD	370.1	400.8	434.0	465.3	494.0	519.2	0.8	0.8	0.7	0.6	0.5
OECD	700.4	770.1	846.8	922.3	994.8	1062.8	0.95	0.95	0.85	0.75	0.7
Latin America	282.6	376.1	495.7	634.5	781.0	924.4	2.9	2.8	2.5	2.1	1.7
Africa	355.5	455.0	871.1	703.0	857.0	994.5	2.5	2.3	2.1	1.9	1.5
Middle East	66.5	85.1	107.9	135.4	165.0	195.3	2.5	2.4	2.3	2.0	1.7
Far E. (ex. Japan)	1053.7	1348.7	1693.0	2084.0	2515.0	2918.7	2.5	2.3	2.1	1.9	1.5
NON-OECD	1758.3	2264.9	2867.7	3556.9	4318.0	5032.9	2.6	2.4	2.15	1.95	1.55
Free World	2458.7	3035.0	3714.5	4479.2	5312.8	6095.7	2.1	2.05	1.9	1.75	1.4
F.W. ex. U.S.	2253.3	2805.9	3458.9	4196.9	5004.0	5761.3	2.2	2.1	1.95	1.8	1.4
U.S.S.R.	243.1	271.2	299.6	330.9	361.9	391.9	1.1	1.0	1.0	0.9	0.8
E. Europe	126.3	136.8	146.7	157.3	167.0	175.5	0.8	0.7	0.7	0.6	0.5
Com. Asia	786.7	913.0	1049.1	1193.8	1345.0	1500.5	1.5	1.4	1.3	1.2	1.1
Com. Bloc	1156.1	1321.0	1495.4	1682.0	1873.9	2067.9	1.35	1.25	1.2	1.1	1.0
World	3614.8	4356.0	5209.9	6161.2	7186.7	8163.6	1.9	1.8	1.7	1.6	1.3

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TABLE 8

WORLD POPULATION DISTRIBUTION (% BASIS)

	1950	1955	1960	1965	1970	1980	1990	2000	2010	2020
U.S.	6.1	6.1	6.0	5.9	5.7	5.3	4.9	4.6	4.3	4.1
Canada	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Japan	3.3	3.3	3.1	3.0	2.9	2.6	2.4	2.2	2.1	2.0
European OECD	12.2	11.7	11.2	10.7	10.2	9.2	8.3	7.6	6.9	6.4
OECD	22.1	21.7	20.9	20.2	19.4	17.7	16.3	15.0	13.8	13.0
Latin America	6.4	6.8	7.1	7.4	7.8	8.6	9.5	10.3	10.9	11.3
Africa	8.7	9.1	9.3	9.5	9.8	10.4	11.0	11.4	11.9	12.2
Middle East	1.6	1.7	1.7	1.8	1.8	2.0	2.1	2.2	2.3	2.4
Far E. (ex. Japan)	26.3	26.2	27.3	28.2	29.1	31.0	32.5	33.8	35.0	35.8
NON-OECD	43.1	43.8	45.4	46.9	48.6	52.0	55.0	57.7	60.1	61.7
Free World	65.3	56.4	66.4	67.1	68.0	69.7	71.3	72.7	73.9	74.7
F.W. ex. U.S.	59.2	59.3	50.4	61.2	62.3	64.4	66.4	67.1	69.6	70.6
U.S.S.R.	7.8	7.2	7.1	7.0	6.7	6.2	5.8	5.4	5.0	4.8
E. Europe	4.2	4.1	3.9	3.7	3.5	3.1	2.8	2.6	2.3	2.1
Com. Asia	22.7	23.2	22.6	22.2	21.8	21.0	20.1	19.4	18.7	18.4
Com. Bloc	34.7	34.6	33.6	32.9	32.0	30.3	28.7	27.3	26.1	25.3
World	100	100	100	100	100	100	100	100	100	100

APPENDIX I

TABLE 9

PROJECTIONS OF CONSTANT DOLLAR GNP AND GNP PER CAPITA

	GNP In Billions Of 1958 Constant $						GNP Per Capita					
	1970	1980	1990	2000	2010	2020	1970	1980	1990	2000	2910	2020
U.S.	723.5	1074	1579	2275	3218	4460	3522	4687	6177	8062	10420	13338
Canada	58.7	94	149	232	355	538	2730	3633	4788	6311	8318	10963
Japan	146.1	333	627	1015	1477	2027	1413	2912	4974	7362	9894	12664
European OECD	548.0	829	1267	1861	2707	3899	1481	2069	2919	4000	5480	7509
OECD	1476.3	2330	3622	5383	7757	10924	2108	3025	4277	5836	7797	10278
Latin America	105.6	182	309	522	854	1359	374	483	624	822	1094	1470
Africa	57.0	93	150	236	368	546	160	205	262	335	429	549
Middle East	17.0	35	70	130	223	355	256	417	648	959	1353	1818
Far E. (ex. Japan)	160.0	275	464	767	1280	2096	152	204	274	368	509	718
NON-OECD	339.6	585	993	1655	2725	4356	193	258	346	465	631	866
Free World	1815.9	2915	4615	7038	10482	15280	739	960	1242	1571	1973	2506
F.W. ex. U.S.	1092.4	1841	3036	4763	7264	10820	485	656	878	1135	1452	1878
U.S.S.R.	364.2	573	893	1391	2125	3153	1498	2113	2980	4203	5872	8046
E. Europe	111.7	171	258	390	585	866	844	1247	1759	2481	3500	4937
Com. Asia	75.6	130	220	371	619	1022	96	142	210	311	460	681
Com. Bloc	551.5	874	1371	2152	3329	5041	477	662	917	1279	1777	2438
World	2367	3789	5986	9190	13811	20321	655	870	1149	1492	1922	2489
World ex. U.S.	1644	2715	4407	6915	10593	15861						

APPENDIX 1

TABLE 10

WORLD GNP DISTRIBUTION (% BASIS)

	1950	1955	1960	1965	1970	1980	1990	2000	2010	2020
U.S.	41.4	38.7	34.3	32.6	30.6	28.3	26.4	24.8	23.3	21.9
Canada	3.2	2.9	2.5	2.3	2.5	2.5	2.5	2.5	2.6	2.6
Japan	1.8	2.3	3.1	4.0	6.2	8.8	10.5	11.0	10.7	10.0
European OECD	24.9	23.6	23.9	24.4	23.1	21.9	21.2	20.3	19.6	19.2
OECD	71.4	67.6	63.7	63.2	62.4	61.5	60.5	58.6	56.2	53.8
Latin America	6.2	5.3	4.8	4.6	4.5	4.8	5.2	5.7	6.2	6.7
Africa	2.5	2.3	2.4	2.3	2.4	2.5	2.5	2.6	2.7	2.7
Middle East	0.4	0.5	0.5	0.6	0.7	0.9	1.2	1.4	1.6	1.7
Far E. (ex. Japan)	6.0	6.1	6.5	6.7	6.8	7.2	7.6	8.3	9.3	10.3
NON-OECD	15.1	14.2	14.3	14.1	14.3	15.4	16.6	18.0	19.7	21.4
Free World	86.5	81.8	78.0	77.4	76.7	76.9	77.1	76.6	75.9	75.2
F.W. ex. U.S.	45.1	43.1	43.7	44.8	46.1	48.6	50.7	51.8	52.6	53.3
U.S.S.R.	-	-	-	-	15.4	15.1	14.9	15.1	15.4	15.5
E. Europe	-	-	-	-	4.7	4.5	4.3	4.2	4.2	4.3
Com. Asia	-	-	-	-	3.2	3.4	3.7	4.0	4.5	5.0
Com. Bloc	13.5	18.2	22.0	22.6	23.3	23.1	22.9	23.4	24.1	24.8
World	100	100	100	100	100	100	100	100	100	100

APPENDIX 1

TABLE 11

PROJECTIONS OF CONSTANT DOLLAR GNP AND GNP PER CAPITA
LOW ECONOMIC GROWTH CASE

	GNP In Billions Of 1958 Constant $						GNP Per Capita					
	1970	1980	1990	2000	2010	2020	1970	1980	1990	2000	2010	2020
U.S.	723.5	1043	1446	1947	2571	3328	3522	4552	5658	6897	8325	9951
Canada	58.7	92	136	197	278	390	2730	3529	4387	5348	6519	7947
Japan	146.1	303	519	727	588	1291	1413	2652	4118	5271	6615	8064
European OECD	548.0	813	1184	1624	2164	2773	1481	2029	2727	3491	4381	5340
OECD	1476.3	2251	3285	4495	6001	7782	2108	2923	3879	4874	6032	7322
Latin America	105.6	180	295	460	690	996	374	479	595	725	884	1077
Africa	57.0	92	144	216	321	453	160	203	252	307	374	456
Middle East	17.0	29	47	76	117	168	256	344	440	563	707	862
Far E. (ex. Japan)	160.0	263	410	615	905	1281	152	195	242	295	360	439
NON-OECD	339.6	564	896	1367	2033	2898	193	249	312	384	471	576
Free World	1815.9	2815	4181	5862	8034	10680	739	928	1126	1309	1512	1752
F.W. ex. U.S.	1092.4	1772	2735	3915	5463	7352	485	632	791	933	1092	1276
U.S.S.R.	364.2	568	843	1192	1635	2159	1498	2093	2813	3601	4519	5509
E. Europe	111.7	169	244	351	477	623	844	1235	1660	2231	2856	3550
Com. Asia	75.6	123	190	290	418	581	95	135	181	243	311	387
Com. Bloc	551.5	860	1277	1833	2530	3363	477	651	854	1090	1350	1626
World	2367.4	3675	5458	7695	10564	14043	655	844	1048	1249	1470	1720
World ex. U.S.	1644	2632	4012	5748	7993	10715						

APPENDIX 1

TABLE 12

WORLD GNP DISTRIBUTION (% BASIS) -- LOW ECONOMIC GROWTH CASE

	1970	1980	1990	2000	2010	2020
U.S.	30.6	28.4	26.5	25.3	24.3	23.7
Canada	2.5	2.5	2.5	2.6	2.6	2.8
Japan	6.2	8.2	9.5	9.4	9.4	9.2
European OECD	23.1	22.1	21.7	21.1	20.5	19.7
OECD	62.4	61.2	60.2	58.4	56.8	55.4
Latin America	4.5	4.9	5.4	6.0	6.5	7.1
Africa	2.4	2.5	2.6	2.8	3.0	3.2
Middle East	0.7	0.8	0.9	1.0	1.1	1.2
Far E. (ex. Japan)	6.8	7.2	7.5	8.0	8.6	9.1
NON-OECD	14.3	15.4	16.4	17.8	19.2	20.6
Free World	76.7	76.6	76.6	76.2	76.0	76.0
F.W. ex. U.S.	46.1	48.2	50.1	50.9	51.7	52.3
U.S.S.R.	15.4	15.4	15.4	15.5	15.5	15.4
E. Europe	4.7	4.6	4.5	4.6	4.5	4.5
Com. Asia	3.2	3.3	3.5	3.7	4.0	4.1
Com. Bloc	23.3	23.4	23.4	23.8	24.0	24.0
World	100	100	100	100	100	100

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TABLE 13

ECONOMIC GROWTH RATE PROJECTIONS FOR PROBABLE AND ALTERNATE LOW CASES

	Probable -- GNP/Cap., % Per Year					Low -- GNP/Cap., % Per Year				
	70/80	80/90	90/00	00/10	10/20	70/80	80/90	90/00	00/10	10/20
U.S.	2.9	2.8	2.7	2.6	2.5	2.6	2.2	2.0	1.9	1.8
Canada	2.9	2.8	2.8	2.8	2.8	2.6	2.2	2.0	2.0	2.0
Japan	7.5	5.5	4.0	3.0	2.5	6.5	4.5	2.5	2.3	2.0
European OECD	3.4	3.3	3.2	3.2	3.2	3.2	3.0	2.5	2.3	2.0
OECD	3.7	3.5	3.15	2.95	2.8	3.3	2.9	2.3	2.1	2.0
Latin America	2.6	2.6	2.8	2.9	3.0	2.5	2.2	2.0	2.0	2.0
Africa	2.5	2.5	2.5	2.5	2.5	2.4	2.2	2.0	2.0	2.0
Middle East	5.0	4.5	4.0	3.5	3.0	3.0	2.5	2.5	2.3	2.0
Far E. (ex. Japan)	3.0	3.0	3.2	3.3	3.5	2.5	2.2	2.0	2.0	2.0
NON-OECD	2.95	3.0	3.0	3.1	3.2	2.7	2.3	2.1	2.05	2.0
Free World	2.7	2.6	2.4	2.3	2.4	2.3	1.95	1.5	1.5	1.5
F.W. ex. U.S.	3.1	2.95	2.6	2.5	2.6	2.7	2.3	1.7	1.6	1.6
U.S.S.R.	3.5	3.5	3.5	3.4	3.2	3.4	3.0	2.5	2.3	2.0
E. Europe	3.5	3.5	3.5	3.5	3.5	3.4	3.0	3.0	2.5	2.2
Com. Asia	4.0	4.0	4.0	4.0	4.0	3.5	3.0	3.0	2.5	2.2
Com. Bloc	3.3	3.3	3.4	3.3	3.2	3.2	2.8	2.5	2.2	1.9
World	2.9	2.9	2.7	2.6	2.6	2.6	2.2	1.8	1.65	1.6

APPENDIX 1

TABLE 14

RATIOS OF LOW TO MOST PROBABLE GNP PROJECTIONS (% BASIS)

	1975	1980	1985	1990	2000	2010	2020
U.S.	98.6	97.1	94.3	91.6	85.6	79.9	74.6
Canada	98.9	97.9	94.6	91.3	84.9	78.3	72.5
Japan	95.5	91.0	86.9	82.8	71.6	66.9	63.7
European OECD	99.0	98.1	95.8	93.5	87.3	79.9	71.1
OECD	98.3	96.6	93.7	90.7	83.5	77.4	71.2
Latin America	99.4	98.9	97.2	95.5	88.1	80.8	73.3
Africa	99.5	98.9	97.5	96.0	91.5	87.2	83.0
Middle East	91.4	82.6	75.0	67.1	58.5	52.5	47.3
Far E. (ex. Japan)	97.8	95.6	92.0	88.4	80.2	70.7	61.1
NON-OECD	98.2	96.4	93.3	90.2	82.6	74.6	66.5
Free World	98.3	96.6	93.6	90.6	83.3	76.7	69.9
F.W. ex. U.S.	98.1	96.3	93.2	90.1	82.2	75.2	68.0
U.S.S.R.	99.6	99.1	96.8	94.4	85.7	76.9	68.5
E. Europe	99.4	98.8	96.7	94.6	90.0	81.5	71.9
Com. Asia	97.3	94.6	90.5	86.4	78.2	67.5	56.9
Com. Bloc	99.2	98.4	95.8	93.1	85.2	76.0	66.7
World	98.5	97.0	94.1	91.2	83.7	76.5	69.1
World ex. U.S.	98.5	96.9	94.0	91.0	83.1	75.5	67.6

APPENDIX 2

ENERGY PROJECTIONS

A.2.1 Sources of Historical Data

The United Nations publishes "World Energy Supplies" on a periodic basis. The Statistical Papers Series J, Nos. 1-12, provide historical data on the worldwide production and consumption of energy by fuel type and in terms of "coal equivalent." The statistics are based on the heat energy that the various fuel sources would produce under ideal conditions (even though actual usage may be much less efficient). The underlying assumption is that a metric ton of "coal equivalent" has a heat content of 27.3×10^6 BTU.

It must be pointed out that there are discrepancies between the U.N. statistics and other sources of data. For example, the U.N. reported the following U.S. consumption of energy in 1964:

	Coal and Lignite	Liquid Fuels	Natural Gas	Hydro + Nuclear	Total Consumption
10^6 MT of C.E.	402.8	692.3	594.3	28.1	1712.5
10^{15} BTU	11.00	18.90	16.22	0.63	46.75

However, the U.S. Bureau of Mines reported the following in Information Circular 8384 (July 1968):

10^{15} BTU	11.66	22.38	15.65	1.91	51.60

Part of the discrepancy is because the U.N. deals with Hydro and Nuclear power on an energy output basis while the Bureau of Mines uses an input basis that takes account of the efficiency of converting other forms of energy to electricity. However, this source of difference may be eliminated by comparing only the fossil fuel portion of total energy input:

	U.N.	U.S.B.M.
Total F.F. Input, 10^{15} BTU	46.12	49.69

The main reason for this difference is that the U.N. statistics exclude "bitumens, paraffin wax, road oils, petrochemical feedstocks, and petroleum coke" while the U.S.B.M. figures include these non-energy uses of fossil fuels. The latter account for about 11% of total U.S. fossil fuel demand, a figure that is consistent with the percentage differences between U.N. and U.S.B.M. data as shown in Table 1.

The U.S.B.M. data are preferred for the U.S. but it is necessary to utilize the U.N. statistics for foreign energy demand. Provided that a similar or consistent differential exists, it is possible to convert the U.N. data to a U.S.B.M. basis, thereby permitting comparisons, correlations, and projections to be made in a consistent way.

Table 2 provides data for the "World ex-U.S." for petroleum consumption including (I.P. basis) and excluding (U. N. basis) non-fuel products. When these data are weighted back onto a total fossil fuel basis, the differences for 1960 and 1965 approximate 6.0% and 9.5%, respectively. The latter figure is similar to the differential found for the U.S., and the rising percentage from 1960 to 1965 is consistent with the increasing importance of petroleum relative to total fossil fuels and also the expanding production of petrochemicals in the "World ex-U.S." Thus, it is believed conversion of the U.N. statistics to a U.S.B.M. basis is reasonable, and that in subsequent years similar trends will apply inside and outside the U.S.

A.2.2 Energy Demand/GNP Correlations

Historical data for total energy demand are given in Table 3 and presented on a percentage basis in Table 4. The same data may be combined with constant dollar GNP statistics to derive conversion factors for metric tons of coal equivalent per $1,000 of constant dollar GNP, as shown in Table 5. Extrapolation of the trends in these factors projects the future relationship between total energy demand and GNP. A constant ratio is indicated for the U.S. because gains in efficiency in some directions are being offset by lower efficiency elsewhere. A principal factor in lowering efficiency is due to the conversion losses associated with electricity generation combined with an increasing demand for energy in the form of electricity. These factors are counterbalanced by gains in the efficiency of energy use (except for electricity generation). Eventual gains in generating efficiency are expected from the application of MHD and commercial use of breeder reactors. However, neither factor is expected to have a significant impact on the overall efficiency of energy use in the U.S. before the end of the century.*

All foreign areas are expected to improve their overall efficiency of energy usage relative to GNP. The Communist countries are expected to reach parity with the U.S. in this respect sometime after the year 2000. The relatively poor current ratio (3.35 MT of C.E. per $1,000 of GNP) is partly due to (inefficient) combustion of solid fuels (still 53% of total energy input versus 22% in the U.S.). This factor will improve as oil and gas rapidly diminish the percentage contribution of solid fuels to total energy supplies in Communist countries. However, another factor is the great distances over which energy must be transported in the Soviet Union. A similar situation exists in the U.S. Consequently, it is very unlikely that the statistical efficiency of total energy use in either the U.S.S.R. or the U.S. will ever be as high as that in W. Europe and Japan. The latter areas have short lines of land communications and, hence, lower electricity transmission losses, etc. But this is not the only reason that the current ratio of 2.22 MT of C.E. per $1,000 of GNP is lower than the 3.06 ratio for the U.S. (even after making allowance for the fact that the latter is above its 2.95 trend line due to the recession-induced decline in industrial production). In the "Free World ex-U.S.", both energy demand and GNP generation are concentrated in W. Europe and Japan. Both areas must export higher percentages of manufactured goods than the U.S. in order to pay for necessary imports including energy supplies. Thus, energy usage is more concentrated on industrial production (and less on private transportation) than in the U.S., thereby achieving a lower energy/GNP ratio. Nevertheless, significant further improvements in the ratio are not expected.

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* Combined gas turbine/steam turbine cycles may begin to improve the conversion efficiency in new installations much sooner, and may forestall the commercial development of MHD.

In summary, the energy/GNP ratio outside the U.S. is expected to improve mainly because of a slowly improving overall ratio in the Communist Bloc. This, together with the fact that GNP is increasing faster outside the U.S. than domestically, may be expected to improve the world ratio slightly (from 2.74 to 2.53 over the next 50 years).

The consequences of the above trends are illustrated by the calculations given in Table 6 and summarized in Table 7. These calculations are based on GNP projections considered to be most probable. However, an alternate "low economic growth case" has also been considered. Energy demand associated with the latter is summarized in Table 8.

A.2.3 U.S. Fossil Fuel Demand

Historical data for U.S. consumption of fossil fuels are given in Table 9. The breakdown is by heat content and the percentage contributed by coal, oil, and gas. The percentage of total demand supplied by each fuel type is projected in Table 10.

Total U.S. energy supply is projected in Table 11, making use of the data and projections in Tables 6, 9 and 10. This makes it possible to convert the projected supplies of fossil fuels from a heat content to a metric ton basis, as shown in Table 12.

A.2.4 Foreign Fossil Fuel Demand

Procedures exactly similar to those used in the preceding sections lead to the historical and projected consumption of fossil fuels recorded in Table 13. The data are for the "Free World ex-U.S." and for the Communist Bloc countries as aggregates, and are expressed on a percentage basis.

The percentage data are converted to a metric ton basis in the top half of Table 14, using assumptions paralleling those listed in Table 12. The bottom half of Table 14 summarizes the worldwide projections of fossil fuel consumption by fuel type.

A.2.5 World Energy Demand

The projections made in the two previous sections are summarized in Tables 15 and 16. The former records the projected percentage contribution of each energy source, while the latter presents the same data in terms of quadrillions of BTU's of input energy rather than on the metric tonnage basis used in Table 14.

APPENDIX 2

TABLE 1

COMPARISON BETWEEN U.N. AND U.S.B.M. ENERGY CONSUMPTION STATISTICS FOR THE U.S.

	Total Fossil Fuel Input				
	U.N.*		U.S.B.M.**	U.S.B.M. - U.N.	
Year	10^6 MT of C.E.	10^{15} BTU	10^{15} BTU	10^{15} BTU	% Diff.
1955	1270.0	34.67	38.46	3.79	10.9
1956	1318.0	35.98	40.41	4.43	12.3
1957	1316.8	35.93	40.35	4.42	12.3
1958	1313.5	35.86	40.30	4.44	12.4
1959	1368.9	37.37	41.81	4.44	11.9
1960	1434.6	39.16	43.18	4.02	10.3
1961	1458.5	39.82	43.93	4.11	10.3
1962	1524.5	41.62	45.93	4.31	10.4
1963	1589.4	43.39	47.88	4.47	10.3
1964	1689.4	46.12	49.69	3.57	7.7
1965	1765.7	48.20	51.70	3.50	7.3

* Statistical Papers, Series J, Nos. 1-12.

** Information Circular 8384, July 1968.

APPENDIX 2

TABLE 2

RECONCILIATION OF U.N. AND PETROLEUM INFORMATION BUREAU STATISTICS FOR PETROLEUM CONSUMPTION

- Consumption of Petroleum Products

	10^6 MT		10^{15} BTU	
	1960	1965	1960	1965
World	1045.9	1543.0	42.83	63.19
U.S.	460.4	553.0	18.85	22.65
World ex-U.S.	585.5	990.0	23.98	40.54

Source: Institute of Petroleum Review, October 1970.

- Consumption of Liquid Fuels

	10^6 MT of C.E.		10^{15} BTU	
	1960	1965	1960	1965
World	1322.9	1920.3	36.12	52.42
U.S.	593.3	723.7	16.20	19.75
World ex-U.S.	729.6	1196.6	19.92	32.67

Source: U.N. Statistical Papers, Series J.

- Differential between I.P. and U.N. Statistics	1960	1965
(Due to exclusion of non-fuel products from U.N. data)	4.06	7.87
% Difference	20.4	24.1

APPENDIX 2

TABLE 3

WORLD ENERGY CONSUMPTION BY SOURCE IN MILLION METRIC TONS OF COAL EQUIVALENT

Area	Year	Coal	Oil	Gas	Hydro + Nuclear	Total
World	1950	1,569	636	273	41	2,519
	1955	1,816	948	397	59	3,220
	1960	2,204	1,323	620	87	4,234
	1965	2,251	1,920	933	118	5,222
	1970 E	2,160	2,822	1,335	168	6,485
U.S.	1950	444	337	249	14	1,044
	1955	404	515	351	15	1,285
	1960	359	593	482	19	1,453
	1965	425	724	617	25	1,791
	1970 E	480	905	785	45	2,215
Communist Bloc	1950	317	54	14	2	387
	1955	656	106	21	4	787
	1960	1,087	192	75	10	1,364
	1965	1,054	295	196	17	1,562
	1970 E	980	497	350	23	1,850
Free World	1950	1,252	582	259	39	2,132
	1955	1,160	842	376	55	2,433
	1960	1,117	1,131	545	77	2,870
	1965	1,197	1,625	737	101	3,660
	1970 E	1,180	2,325	985	145	4,635
F.W. ex-U.S.	1950	808	245	10	25	1,088
	1955	757	328	25	39	1,148
	1960	758	538	62	57	1,415
	1965	772	902	120	75	1,870
	1970 E	700	1,420	200	100	2,420
World ex-U.S.	1950	1,125	299	24	27	1,475
	1955	1,412	433	46	44	1,935
	1960	1,845	730	138	68	2,781
	1965	1,826	1,196	316	93	3,431
	1970 E	1,680	1,917	550	123	4,270

Source: U.S. Statistical Papers, with extrapolation to 1970.

APPENDIX 2

TABLE 4

WORLD ENERGY CONSUMPTION BY SOURCE (% BASIS)

Area	Year	Coal	Oil	Gas	H + N	Total
World	1950	62.4	25.2	10.8	1.6	100
	1955	56.5	29.4	12.3	1.8	100
	1960	52.2	31.2	14.6	2.0	100
	1965	43.1	36.7	17.9	2.3	100
	1970 E	33.3	43.5	20.6	2.6	100
U.S.	1950	42.5	32.3	23.9	1.3	100
	1955	31.4	40.1	27.3	1.2	100
	1960	24.7	40.8	33.2	1.3	100
	1965	23.8	40.4	34.4	1.4	100
	1970 E	21.7	40.9	35.4	2.0	100
Communist Bloc	1950	81.9	14.0	3.6	0.5	100
	1955	83.2	13.5	2.7	0.6	100
	1960	79.7	14.0	5.5	0.8	100
	1965	67.5	18.8	12.6	1.1	100
	1970 E	53.0	26.9	18.9	1.2	100
Free World	1950	58.8	27.3	12.1	1.8	100
	1955	47.7	34.6	15.4	2.3	100
	1960	38.9	39.4	19.0	2.7	100
	1965	32.7	44.4	20.1	2.8	100
	1970 E	25.5	50.1	21.3	2.1	100
F.W. ex-U.S.	1950	74.3	22.5	0.9	2.3	100
	1955	65.8	28.6	2.2	3.4	100
	1960	53.6	38.0	4.4	4.0	100
	1965	41.3	48.3	6.4	4.0	100
	1970 E	29.0	58.6	8.3	4.1	100
World ex-U.S.	1950	76.3	20.3	1.6	1.8	100
	1955	72.9	22.4	2.4	2.3	100
	1960	66.4	26.2	5.0	2.4	100
	1965	53.2	34.9	9.2	2.7	100
	1970 E	39.3	44.9	12.9	2.9	100

Based on statistics in Table 3.

APPENDIX 2

TABLE 5

CORRELATION OF TOTAL ENERGY CONSUMPTION WITH GNP IN 1958 CONSTANT DOLLARS

Area	Year	10^6 MT of C.E.	GNP 10^9 $	MT of C.E. per $1,000
World	1950	2,519	858.5	2.93
	1955	3,220	1,131	2.85
	1960	4,234	1,423	2.98
	1965	5,222	1,897	2.75
	1970	6,485	2,367	2.74
U.S.	1950	1,044	355.3	2.94
	1955	1,285	438.0	2.93
	1960	1,454	487.7	2.98
	1965	1,791	617.8	2.90
	1970	2,215	723.5	3.06
Communist Bloc	1950	387	116	3.34
	1955	787	206	3.82
	1960	1,364	313	4.36
	1965	1,562	429	3.64
	1970	1,850	551.5	3.35
Free World	1950	2,132	742.5	2.87
	1955	2,433	925.0	2.63
	1960	2,870	1,110	2.59
	1965	3,660	1,468	2.49
	1970	4,635	1,816	2.55
F.W. ex-U.S.	1950	1,088	387.2	2.81
	1955	1,148	487.0	2.36
	1960	1,415	622.2	2.27
	1965	1,870	850.1	2.20
	1970	2,420	1,092.4	2.22
World ex-U.S.	1950	1,431	503.2	2.84
	1955	2,072	693	2.99
	1960	2,819	935	3.01
	1965	3,352	1,279	2.62
	1970	4,065	1,643	2.47

APPENDIX 2

TABLE 6

TOTAL ENERGY DEMAND BASED ON GNP PROJECTIONS

		1970 Energy	1970 GNP	1980 GNP	Conversion Factor	1980 Energy	Energy Inc. % Per Yr.
• 1980	U.S.	2,215	724	1,074	2.95	3,168	3.65
	F.W. ex-U.S.	2,420	1,092	1,841	2.18	4,013	5.15
	F.W.	4,635	1,816	2,915	2.46	7,181	4.5
	Com. Bloc	1,850	551	874	3.20	2,797	4.3
	World	6,485	2,367	3,789	2.63	9,978	4.4
		1980	1980	1990	Factor	1990	
• 1990	U.S.	3,168	1,074	1,579	2.95	4,658	3.9
	F.W. ex-U.S.	4,013	1,841	3,036	2.17	6,588	5.1
	F.W.	7,181	2,915	4,615	2.44	11,246	4.6
	Com. Bloc	2,797	874	1,371	3.10	4,250	4.3
	World	9,978	3,789	5,986	2.59	15,496	4.5
		1990	1990	2000	Factor	2000	
• 2000	U.S.	4,658	1,579	2,275	2.95	6,711	3.7
	F.W. ex-U.S.	6,588	3,036	4,763	2.17	10,336	4.6
	F.W.	11,246	4,615	7,038	2.42	17,047	4.25
	Com. Bloc	4,250	1,371	2,152	3.03	6,520	4.4
	World	15,496	5,986	9,190	2.56	23,567	4.3
		2000	2000	2010	Factor	2010	
• 2010	U.S.	6,711	2,275	3,218	2.95	9,493	3.5
	F.W. ex-U.S.	10,336	4,763	7,264	2.17	15,763	4.3
	F.W.	17,047	7,038	10,482	2.41	25,256	4.0
	Com. Bloc	6,520	2,152	3,329	2.97	9,887	4.25
	World	23,567	9,190	13,811	2.54	35,143	4.1
		2010	2010	2020	Factor	2020	
• 2020	U.S.	9,493	3,218	4,460	2.95	13,157	3.3
	F.W. ex-U.S.	15,763	7,264	10,820	2.17	23,479	4.1
	F.W.	25,256	10,482	15,280	2.40	36,636	3.8
	Com. Bloc	9,887	3,329	5,041	2.92	14,720	4.1
	World	35,143	13,811	20,321	2.53	51,356	3.9

Notes: Energy demand expressed in 10^6 MT of Coal Equivalent.
Conversion factor transforms GNP projection to energy demand.

APPENDIX 2

TABLE 7

PROJECTIONS OF TOTAL ENERGY DEMAND

	Billion Metric Tons of Coal Equivalent							
	1970	1975	1980	1985	1990	2000	2010	2020
U.S.	2.22	2.66	3.17	3.82	4.66	6.71	9.49	13.16
Free World ex-U.S.	2.42	3.12	4.01	5.14	6.59	10.34	15.76	23.48
Free World	4.64	5.78	7.18	8.96	11.25	17.05	25.26	36.64
Communist Bloc	1.85	2.28	2.80	3.45	4.25	6.52	9.89	14.72
World	6.49	8.06	9.98	12.41	15.50	23.57	35.14	51.36
World ex-U.S.	4.27	5.40	6.81	8.59	10.84	16.86	25.65	38.20

- 1970-2000 Growth Rate Summary

	Ratio	% per Yr.
U.S.	3.03	3.8
F.W. ex-U.S.	4.27	5.0
Free World	3.68	4.4
Com. Bloc	3.52	4.3
World	3.63	4.4
World ex-U.S.	3.95	4.7

Source: Based on Table 6.

APPENDIX 2

TABLE 8

PROJECTIONS OF TOTAL ENERGY DEMAND - LOW ECONOMIC GROWTH CASE

	Trillion Metric Tons of Coal Equivalent							
	1970	1975	1980	1985	1990	2000	2010	2020
U.S.	2.22	2.62	3.08	3.60	4.26	5.74	7.58	9.82
Free World ex-U.S.	2.42	3.06	3.86	4.79	5.93	8.50	11.85	15.97
Free World	4.64	5.68	6.94	8.39	10.19	14.24	19.43	25.79
Communist Bloc	1.85	2.26	2.75	3.30	3.96	5.55	7.52	9.82
World	6.49	7.94	9.69	11.69	14.15	19.79	26.95	35.61
World ex-U.S.	4.27	5.32	6.61	8.09	9.89	14.05	19.37	25.79

- 1970-2000 Growth Rate Summary

	Ratio	% Per Yr.
U.S.	2.59	3.2
F.W. ex-U.S.	3.51	4.3
Free World	3.07	3.8
Com. Bloc	3.00	3.7
World	3.05	3.8
World ex-U.S.	3.29	4.05

APPENDIX 2

TABLE 9

U.S. FOSSIL FUEL CONSUMPTION BY FUEL TYPE

		Coal	Oil	Gas	Total
• Heat Content Basis 10^{15} BTU	1950	12.91	13.49	6.15	32.55
	1955	11.70	17.52	9.23	38.45
	1960	10.41	20.07	12.70	43.18
	1965	12.36	23.21	16.14	51.71
	1970	13.55	29.66	22.70	65.91
• Percentage Basis	1950	39.7	41.4	18.9	100
	1955	30.4	45.6	24.0	100
	1960	24.1	46.5	29.4	100
	1965	23.9	44.9	31.2	100
	1970	20.6	45.0	34.4	100

Sources: U.S. Bureau of Mines.
Oil and Gas Journal, 3/22/71, p. 61.

APPENDIX 2

TABLE 10

PROJECTION OF U.S. FOSSIL FUEL CONSUMPTION BY FUEL TYPE

- Percentage Basis

	Coal and Shale*	Oil	Gas	Total
1970	20.6	45.0	34.4	100
1975	20.0	45.6	34.4	100
1980	20.0	45.6	34.4	100
1985	20.3	45.8	33.9	100
1990	20.7	46.0	33.3	100
2000	22.0	45.2	32.8	100
2010	23.2	44.5	32.3	100
2020	25.0	43.5	31.5	100

* Includes all solid fuels converted to liquids and gas.

Based on extrapolation of data in Table 9 in the light of U.S.B.M. and other data.

APPENDIX 2

TABLE 11

PROJECTIONS OF U.S. ENERGY SUPPLY BY ENERGY SOURCE

Year	Total Demand 10^{15} BTU*	Hydro(1)	Nuclear(2)	Hydro + Nuclear	Fossil Fuels(3)	Coal and Shale(4)	Oil(4)	Gas(4)
1970	68.81	2.70	0.20	2.90	65.91	13.55	29.66	22.70
1975	82.50	2.92	1.35	4.27	78.23	15.65	35.67	26.91
1980	98.41	3.15	9.47	12.62	85.79	17.16	39.12	29.51
1985	119.08	3.55	20.40	23.95	95.13	19.31	43.57	32.25
1990	144.66	3.96	30.66	34.62	110.04	22.78	50.62	36.64
2000	208.3	4.7	53.2	57.9	150.4	33.1	68.0	49.3
2010	294.6	5.4	86.8	92.2	202.4	47.0	90.0	65.4
2020	408.0	6.0	141.3	147.3	260.7	65.2	113.4	82.1

* Based on Tables 6, 9 and 10.

(1) By extrapolation; excluding pumped storage.

(2) Projections based on trends established by National Power Survey for 1980 and 1990.

(3) By subtraction of Hydro + Nuclear from Total Demand.

(4) By multiplying Fossil Fuel total by percentages from Table 10.

APPENDIX 2

TABLE 12

PROJECTIONS OF U.S. FOSSIL FUEL CONSUMPTION IN METRIC TONS

Year	Million Metric Tons		
	Coal + Shale(1)	Oil(2)	Gas(3)
1970	475	729	498
1975	549	876	591
1980	602	961	648
1985	678	1,070	708
1990	799	1,244	805
2000	1,161	1,670	1,083
2010	1,649	2,211	1,436
2020	2,288	2,786	1,803

Based on Table 11.

(1) Considering shale on a coal equivalent basis, and also correcting back to a current average heat content of 28.5×10^6 BTU per MT.

(2) Converted on an average basis of 40.7×10^6 BTU per MT for U.S. petroleum + NGL.

(3) Converted on the basis of 22.66 MT per 10^6 CF and 1032 BTU/CF, i.e., 10^{15} BTU are equivalent to 21.96×10^6 MT of gas.

APPENDIX 2

TABLE 13

FOSSIL FUEL CONSUMPTION BY FUEL TYPE OUTSIDE THE U.S.

(PERCENTAGE BASIS)

- Historical Data

(U.N. **Basis**, Excluding Non-Energy Uses of Fossil Fuels)

Year	Free World ex-U.S.			Communist Bloc		
	Coal	Oil	Gas	Coal	Oil	Gas
1950	76.0	23.0	1.0	82.4	14.0	3.6
1955	68.2	29.5	2.3	83.8	13.5	2.7
1960	55.8	39.6	4.6	80.3	14.2	5.5
1965	43.0	50.3	6.7	68.2	19.1	12.7

- Projections

(Total F.F. Demand Basis, Including All Uses of Fossil Fuels)

Year	Free World ex-U.S.			Communist Bloc		
	Coal	Oil	Gas	Coal	Oil	Gas
1970	27.2	65.1	7.7	53.0	28.7	18.3
1975	20.0	69.0	11.0	41.0	34.0	25.0
1980	15.0	70.5	14.5	34.0	37.0	29.0
1985	11.5	70.5	18.0	28.0	39.5	32.5
1990	9.5	69.0	21.5	23.4	40.6	36.0
2000	7.0	64.5	28.5	17.0	42.0	41.0
2010	5.0	60.0	35.0	12.1	42.9	45.0
2020	3.4	54.0	42.6	9.0	43.0	48.0

APPENDIX 2

TABLE 14

PROJECTIONS OF FOREIGN FOSSIL FUEL CONSUMPTION IN MILLION METRIC TONS

	Free World ex-U.S.			Communist Bloc			World ex-U.S.		
Year	Coal	Oil	Gas	Coal	Oil	Gas	Coal	Oil	Gas
1970	711	1,144	121	991	359	205	1,702	1,503	326
1975	674	1,563	222	941	523	345	1,615	2,086	567
1980	637	2,015	369	952	698	488	1,589	2,713	857
1985	608	2,494	569	952	902	663	1,560	3,396	1,232
1990	608	2,973	828	952	1,106	878	1,560	4,079	1,706
2000	634	3,916	1,548	952	1,580	1,377	1,586	5,496	2,925
2010	648	5,226	2,725	952	2,265	2,126	1,600	7,491	4,851
2020	667	6,911	4,203	952	3,042	3,035	1,619	9,953	7,238

Based on Table 13 and assumptions paralleling those in Table 12.

- Projections of World Consumption of Fossil Fuels

Year	Coal	Oil	Gas	Total
1970	2,177	2,232	824	5,233
1975	2,164	2,962	1,158	6,284
1980	2,191	3,674	1,505	7,370
1985	2,238	4,466	1,940	8,644
1990	2,359	5,323	2,511	10,193
2000	2,747	7,166	4,008	13,921
2010	3,249	9,702	6,287	19,238
2020	3,907	12,739	9,041	25,687

Based on Table 12 and projections in top half of this table.

APPENDIX 2

TABLE 15

TOTAL ENERGY INPUT BY SOURCE (PERCENTAGE BASIS)

	Coal	Oil	Gas	Hydro + Nuclear
• U.S.				
1970	19.6	43.2	33.0	4.2
1980	17.5	39.7	30.0	12.8
1990	15.8	35.0	25.3	23.9
2000	15.9	32.6	23.7	27.8
2010	16.0	30.5	22.2	31.3
2020	16.0	27.8	20.1	36.1
• Free World ex-U.S.				
1970	25.6	61.5	7.3	5.6
1980	13.9	65.3	13.4	7.4
1990	8.0	58.7	18.3	15.0
2000	5.3	49.3	21.8	23.6
2010	3.6	43.1	25.2	28.1
2020	2.5	38.3	26.0	33.2
• Communist Bloc				
1970	51.7	28.0	18.0	2.3
1980	32.9	35.9	28.1	3.0
1990	21.7	37.5	33.3	7.5
2000	14.1	35.0	34.1	16.8
2010	9.3	33.0	34.8	22.9
2020	6.3	29.8	33.3	30.6
• World				
1970	30.4	46.2	19.1	4.3
1980	20.0	49.4	22.6	8.0
1990	14.0	46.0	24.2	15.8
2000	10.7	40.7	25.5	23.1
2010	8.5	37.0	26.8	27.6
2020	7.0	33.3	26.4	33.3

APPENDIX 2

TABLE 16

PROJECTION OF TOTAL ENERGY INPUT

(10^{15} BTU)

	Coal	Oil	Gas	Total Fossil F.	Hydro + Nuclear	Total
• U.S.						
1970	13.5	29.7	22.7	65.9	2.9	68.8
1975	15.6	35.7	26.9	78.2	4.3	82.5
1980	17.2	39.1	29.5	85.8	12.6	98.4
1985	19.3	43.6	32.2	95.1	24.0	119.1
1990	22.8	50.6	36.6	110.0	34.6	144.6
2000	33.1	68.0	49.3	150.4	57.9	208.3
2010	47.0	90.0	65.4	202.4	92.2	294.6
2020	65.2	113.4	82.1	260.7	147.3	408.0
• Free World ex-U.S.						
1970	19.4	46.6	5.5	71.5	4.3	75.8
1975	18.4	63.6	10.1	92.1	5.6	97.7
1980	17.4	82.0	16.8	116.2	9.3	125.5
1985	16.6	101.5	25.9	144.0	16.9	160.9
1990	16.6	121.0	37.7	175.3	31.0	206.3
2000	17.3	159.4	70.5	247.2	76.3	323.5
2010	17.7	212.7	124.1	354.5	138.5	493.0
2020	18.2	281.3	191.4	491.0	244.0	735.0
• Communist Bloc						
1970	27.0	14.6	9.4	51.0	1.2	52.2
1975	25.7	21.3	15.7	62.7	1.7	64.4
1980	26.0	28.4	23.2	76.6	2.4	79.0
1985	26.0	36.7	30.2	92.9	4.5	97.4
1990	26.0	45.0	40.0	111.0	9.0	120.0
2000	26.0	64.3	62.7	153.0	31.0	184.0
2010	26.0	92.2	96.8	215.0	64.0	279.0
2020	26.0	123.8	138.2	288.0	127.0	415.0
• World						
1970	59.9	90.9	37.6	188.4	8.4	196.8
1980	60.6	149.5	68.5	278.6	24.3	302.9
1990	66.1	216.6	114.3	396.3	74.6	470.9
2000	76.4	291.7	182.5	550.6	165.2	715.8
2010	90.7	394.9	286.3	771.9	294.7	1066.6
2020	109.4	518.5	411.7	1039.7	518.3	1558.0

APPENDIX 3

SULFUR CONTENT OF FOSSIL FUELS

A.3.1 Sulfur Content of Petroleum

All crude oils contain sulfur, mostly in the range of 0.1 to 2.5 wt.% although there are certain crudes that have sulfur contents outside this range.

The average S content for the continental U.S. is approximately 0.6 wt.%. However, the prolific reserves discovered on the North Slope of Alaska approximate 1 wt.% S. In consequence, the weighted average of all domestic crude oils is about 0.75 wt.%.

The average S content of reserves may differ from that of current production. The difference for the Continental U.S. is slight because of the large number of producing fields and the fact that almost all significant discoveries are brought into production as quickly as possible (for economic reasons). However, the North Slope fields are not yet in production. Once production begins, it is evident that the average S content of domestic crude will rise. Thus, the average S content of crude oil reserves can serve as an indicator of the average S in future production. This is the case domestically and abroad.

A.3.1.1 Sulfur Content of U.S. Crude Oils

The average sulfur content of crude oils from more than a hundred of the most important U.S. fields is recorded in Table 1 together with an estimate of the reserves for each field. The latter enable the weighted (by volume) average S content of the reserves to be calculated on a state-by-state basis. The state averages may then be used to calculate the average for the U.S. as shown in Table 2.

Different estimates of "proved reserves" are available from different sources. One such estimate, published by the Oil and Gas Journal, is shown in the second part of Table 2 for comparison with the estimates obtained from the 1971 International Petroleum Encyclopedia. The different sources indicate a somewhat different geographical distribution of reserves, but almost exactly the same average sulfur content:

OGJ	0.59wt.%S
IPE	0.56wt.%S

It is a reasonable assumption that the average S content of the principal U.S. oil fields is respresentative of all domestic fields. On this basis, the Bureau of Mines' data for total crude oil reserves may be used to calculate the average S content of the total domestic reserves as shown in Table 3. The weighted average is 0.58 wt.% for the Continental U.S. and 0.74 wt.% when Alaska reserves are included.

When calculated on a "1970 production" basis rather than on a "reserves" basis. The average S content was 0.56 wt.%, as shown in Table 4.

The top part of Table 3 also lists the reserves of natural gas liquids (NGL). Such reserves are part of the total reserves of petroleum liquids, but their S content is negligible. This has the effect of reducing the average S content of the total domestic reserves of petroleum liquids below the 0.58 wt.% and 0.74 wt.% figures cited above. However, the average BTU content of a barrel of NGL is less than that of a barrel of crude oil. This has to be taken into account when the sulfur content of fossil fuels consumed is calculated from the energy demand for such fuels (expressed on a BTU or on a metric ton basis).

The S content of domestic reserves of petroleum liquids must be distinquished from that of the total U.S. supply of petroleum liquids. The latter includes imported petroleum products and products derived from imported crude oils. Because of vapor pressure or volatility considerations, imported crude oils do not contain NGL*. In consequence, calculation of the S content of the total U.S. petroleum supply requires knowledge or estimates of the components of this supply.

A.3.1.2 Sulfur Content of Foreign Crude Oils

The sulfur content of Canadian crude oils is dealt with on exactly the same basis in the first part of Table 5 as that used for U.S. crude oils. The remainder of the Table presents similar data for other countries. The principal source of this information is the 1971 edition of the International Petroleum Encyclopedia. However, a number of other sources were used as noted. Estimates of sulfur content were made in cases where published information was lacking.

Table 6 draws on the information in Table 5 and presents it on a summarized basis by geographical area. Table 7 is a further summarization that indicates that the average S content of worldwide crude oil reserves is approximately 1.5 wt.%. However, the crude oil actually produced in 1970 had an average S content of about 1.2 wt.%. The principal reasons for the difference between these figures are that the U.S. is producing its reserves much faster than the world average and that the average S content of Continental U.S. crude is only a third of the average of the "World ex U.S.".

Because the world's reserves have a higher average S content (1.49 wt.%) than that of 1970 production (1.21 wt.%), it must be expected that the average S content of crude oil production will increase. The alternative would be to discover new, and enormous, reserves of low sulfur crude oil. While new reserves are likely to be found, it is unlikely that they will be almost exclusively of low S content. Nevertheless, the environmental pressures to reduce the sulfur content of fossil fuels are likely to stimulate both the search for, and production of, low S crudes. Thus, the near term prospects are for maintenance of the world average S content at about the 1970 level.

Additional references to the S content of petroleum are given in Table 8.

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*However, arrangements are being made to import W. Canadian NGL into the U.S. by pipeline.

A.3.2 Sulfur Content of Natural Gas

Worldwide reserves of natural gas are listed on a country-by-country basis in Table 9, and are summarized in Table 10. The reserves were converted from cubic feet to metric tons because the latter measure, taken in conjunction with S concentration in the gas, gives the quantity of sulfur that will be recovered when the gas is produced.

Natural gas reserves include components in addition to H_2S that are removed before the gas is fed into a commercial pipeline. Nitrogen, carbon dioxide, and condensible hydrocarbons are always removed if present in the reservoir gas. Part of the ethane may be removed (for petrochemical feedstock use) before the gas is pipelined.

Gas of "pipeline quality" has a BTU content of slightly more than 1000 BTU/SCF (1025-1030 BTU/CF is typical for the U.S.). Hence, one metric ton of pipeline gas has a heat content of about 45 million BTU. It is convenient to express the S content of natural gas as the quantity of sulfur that would be recovered for each metric ton of gas marketed. It will be appreciated that this is not a true sulfur content, rather it is the quantity of by product S corresponding to the gas actually marketed. This approach makes it easy to calculate the quantity of sulfur that will be recovered when a given amount of energy demand is filled with natural gas.

Published data on natural gas sulfur content are sparse except for W. Canadian gas fields. Thus, the figures presented in Table **11** are based to a large extent on estimates. Fortunately, however, published data do exist for the commercial gas fields that contain the largest quantities of sulfur. These data are recorded in Table **12**. The Western Canadian reserves of 146.5 million MT of S recoverable from natural gas are official statistics that are revised annually.

A.3.3 Sulfur Content of Coal

The sulfur content of U.S. coals, on a state-by-state basis, is listed in Table **13**. Account has been taken of the different caloric contents of the anthracite, bituminous, sub-bituminous and lignite coals that are treated on an aggregated basis in the state totals.

Correction for heat content to a "standard" of 28.9 million BTU/metric ton (typical of U.S. bituminous coals) raises the average S content of U.S. coal reserves from 1.56 wt.% (on an "as found" basis) to 1.71 wt.%. The calculation does not change the S content per se, rather it reduces the the number of tons of "standard" heat content coal. Consequently, on either basis, the sulfur contained in total U.S. coal reserves is estimated to be about 18.7 billion metric tons.

There are differences of opinion as to the fraction of U.S. coal reserves that will prove to be economically recoverable. However, the 18 billion ton figure should be set against a current U.S. sulfur demand of about 10 million tons annually. Thus, U.S. coal reserves have the potential for satisfying U.S. sulfur demand for many years beyond the year 2020 (the terminal year of the Sulfur Model).

Sulfur content data for foreign coals are presented in Table 14. When used in conjunction with more recent Bureau of Mines data for coal reserves, a worldwide summary of average S content of coal may be obtained. Table 15 indicates that Communist countries, particularly the U.S.S.R., also have very large potential reserves of sulfur in their coal reserves.

A.3.4 Sulfur Content Aggregates

It is of interest to note that the average S content of coal, corrected to standard heat content, is about 1.46 wt.%. This figure is essentially the same as the average S content of crude oil, 1.49 wt.%, listed in Table 7. Whether this is pure coincidence or has geological significance is not known. The world average S content of natural gas, as shown in Table 10, is about 0.7 wt.%. This lower average value is due to the fact that many of world's major gas fields are sweet. On the other hand, certain gas fields have H_2S contents as high as 70 mol.%. There is no parallel to such high sulfur levels in either crude oil or coal, unless the Frasch deposits of almost pure sulfur associated with traces of petroleum are considered to be "crude oils with 99% sulfur content".

It is also of possible macrogeological interest that high S content of one type of fossil fuel in a particular area is often accompanied by low S content of another type of fossil fuel. For example, Alberta has high S gas and low S crude oil. The same phenomenon is found in France and Germany. Brazil has very high S coal and very low S petroleum. On the average, the U.S. has high S coal and low S crude. However, Wyoming has low S coal but high S crude oil and natural gas. There are exceptions to these "compensation" generalizations. For example, Indonesia appears to have low S content in oil, gas, and coal. Nevertheless, if large geographical aggregates are used, the average S content of all fossil fuel reserves appears to be about 1.4 wt.%.

Recognizing that oil, gas, and coal have heat contents per metric ton that are significantly different for most purposes (about 40, 45, and 29 million BTU/MT respectively), it is still possible to make an order-of-magnitude generalization that, worldwide, each 2.5 billion BTU of fossil fuel energy "contain" about 1 long ton of sulfur. If future demands for primary energy can be projected, and the quantity expected to be supplied by hydro and nuclear power is deducted, then the remainder is the quantity to be supplied by fossil fuels. This latter quantity may be converted into and order-of-magnitude sulfur recovery potential using the rough equivalency cited above.

APPENDIX 3

TABLE 1
SULFUR CONTENT OF U.S. CRUDE OILS

State or Region	Field	Reserves		Wt % S	S Contribution x 100	State Average
		10^9 bbls	%			
Alaska	McArthur River	0.25	1.2	(0.50)	0.60	
	Swanson River	0.11	0.5	0.50	0.25	
	Prudhoe Bay	20.00	98.3	1.00	98.30	
		20.36	100	0.99	99.15	0.99
Appalachian	Bradford-Allegheny	0.01	2	0.11	0.22	
	Lima-Peru	0.50	98	(0.11)	10.78	
		0.51	100	0.11	11.00	0.11
Arkansas	Smackover	0.03	100	2.1		2.1
Colorado	Rangeley	0.16	100	0.65		0.65
Illinois	Clay City	0.03	34.0	0.19	6.46	
	Loudon	0.02	27.9	0.20	5.58	
	Old Ill.	0.02	22.0	0.17	3.74	
	Salem	0.01	16.1	0.16	2.58	
		0.08	100	0.18	18.36	0.18
Kansas	Bemis-Shutts	0.143	75.3	0.57	42.92	
	Chase Silica	0.016	8.4	0.35	2.94	
	El Dorado	0.007	3.7	0.26	0.96	
	Trapp	0.024	12.6	0.41	5.17	
		0.190	100	0.52	51.99	0.52
Mississippi	Baxterville	0.073	66	2.71	178.86	
	Tinsley	0.037	34	1.02	34.68	
		0.110	100	2.13	218.54	2.13
Montana	Bell Creek	0.175	69.2	(0.90)	62.28	
	Cut Bank	0.078	30.8	0.91	28.03	
		0.253	100	0.90	90.31	0.90

APPENDIX 3

TABLE 1 (CONTINUED)
SULFUR CONTENT OF U.S. CRUDE OILS

State or Region	Field	Reserves 10^9 bbls	Reserves %	Wt % S	S Contribution x 100	State Average
California	Belridge	0.07	1.04	0.23	0.239	
	Brea-Olinda	0.04	0.60	0.75	0.450	
	Buena Vista	0.06	0.89	0.59	0.525	
	Coalinga	0.07	1.04	0.75	0.780	
	Coalinga Nose	0.07	1.04	0.25	0.260	
	Coyote W.	0.02	0.30	0.82	0.246	
	Cuyama S.	0.03	0.44	0.42	0.185	
	Dominguez	0.02	0.30	0.96	0.288	
	Elk Hills	1.02	15.18	0.68	10.302	
	Huntington Beach	0.14	2.08	1.57	3.266	
	Inglewood	0.04	0.60	2.50	1.500	
	Kern River	0.20	2.97	1.19	3.534	
	Kettleman	3.15	46.88	0.50	28.440	
	Long Beach	0.03	0.44	1.29	0.568	
	Midway-Sunset	0.27	4.02	0.94	3.779	
	San Ando	0.10	1.49	(2.25)	3.353	
	Santa Fe Springs	0.02	0.30	2.25	0.675	
	Torrance	0.02	0.30	(0.90)	0.270	
	Ventura	0.07	1.04	0.33	0.343	
	Wilmington	1.28	19.05	1.00	19.050	
		6.72	100	0.73	73.053	0.73
Louisiana (onshore)	Bayou Sale	0.060	1.80	0.16	0.288	
	Caddo-Pine I.	0.093	2.80	0.27	0.756	
	Caillou I.	2.475	74.42	0.23	17.117	
	Delhi	0.072	2.16	0.08	0.173	
	Golden Meadow	0.095	2.86	0.18	0.515	
	Grand Bay	0.093	2.80	0.31	0.868	
	Lafitte	0.053	1.59	0.30	0.477	
	Lake Barre	0.108	3.25	0.49	1.593	
	Lake Washington	0.138	4.15	0.37	1.536	
	Weeks I.	0.064	1.92	0.18	0.346	
	West Bay	0.075	2.25	0.27	0.608	
		3.326	100	0.24	24.277	0.24
(offshore)	Bay Marchand (BL. 2)	0.230	16.5	0.46	7.59	
	Main Pass (BL. 69)	0.162	11.6	0.16	1.86	
	South Pass (BL. 24)	0.428	30.9	0.26	8.03	
	South Pass (BL. 27)	0.134	9.6	0.37	3.55	
	Timbalier Bay	0.230	16.5	0.26	4.29	
	West Delta (BL. 30)	0.207	14.9	0.33	4.92	
		1.391	100	0.30	30.24	0.30

APPENDIX 3

TABLE 1 (CONTINUED)
SULFUR CONTENT OF U.S. CRUDE OILS

State or Region	Field	Reserves 10⁹ bbls	Reserves %	Wt % S	S Contribution x 100	State Average
New Mexico	Nobbs	0.026	15.3	1.41	21.57	
	Monument	0.050	29.4	1.39	40.87	
	Vacuum	0.094	55.3	0.10	5.53	
		0.170	100	0.68	67.97	0.68
Oklahoma	Burbank	0.019	1.60	0.24	0.38	
	Cushing	0.012	1.01	0.25	0.25	
	Glenn Pool	0.022	1.85	0.27	0.50	
	Golden Trend	0.148	12.46	0.14	1.74	
	Healdton	0.015	1.26	0.93	1.17	
	Hewitt	0.016	1.35	0.84	1.13	
	Okla. City	0.034	2.86	0.16	0.46	
	Seminole	0.727	61.20	(0.25)	15.30	
	St. Louis	0.005	0.42	0.11	0.05	
	Sho-Vel-Tum	0.060	5.05	(0.11)	0.56	
	Sooner Trend	0.130	10.94	(0.11)	1.20	
		1.188	100	0.23	22.74	0.23
Utah	**Aneth**	0.231	100	0.20		0.20
Wyoming	Elk Basin	0.034	13.1	0.10	1.31	
	Hamilton Dome	0.059	22.7	3.07	69.69	
	Hilight	0.099	38.1	0.10	3.81	
	Oregon Basin	0.041	15.8	3.25	51.35	
	Salt Creek	0.027	10.3	2.36	24.31	
		0.260	100	1.50	150.47	1.50
Texas	Anahuac	0.065	0.99	0.15	0.15	
	Aqua Dulce	0.045	0.68	0.08	0.05	
	Cogdell	0.066	1.00	(1.80)	1.80	
	Conroe	0.146	2.22	0.33	0.73	
	Cowden N.	0.034	0.52	1.90	0.99	
	Cowden S.	0.063	0.96	1.77	1.70	
	Diamond M	0.331	5.03	0.20	1.01	
	E. Texas	2.129	32.35	0.31	10.03	
	Fullerton	0.064	0.97	2.08	2.03	
	Fairway	0.149	2.26	(0.15)	0.34	
	Goldsmith	0.041	0.62	0.16	0.10	
	Hastings	0.225	3.42	0.19	0.65	
	Hawkins	0.155	2.36	2.19	5.17	
	Hendrick	0.022	0.33	1.73	0.57	
	Howard Glasscock	0.042	0.64	1.18	0.76	
	Hull-Merchant	0.058	0.88	0.35	0.31	
	Kelly-Snyder	0.718	1.09	0.24	0.26	

APPENDIX 3

TABLE 1 (CONTINUED)
SULFUR CONTENT OF U.S. CRUDE OILS

State or Region	Field	Reserves 10^9 bbls	Reserves %	Wt % S	S Contribution x 100	State Average
Texas (Continued)	Keystone	0.061	0.93	0.65	0.60	
	Levelland	0.068	1.03	2.12	2.18	
	McElroy	0.083	1.26	2.37	2.99	
	Midland Farms	0.061	0.93	0.03	0.03	
	Old Ocean	0.065	0.99	0.21	0.21	
	Panhandle	0.430	6.54	0.13	0.85	
	Seeligson	0.110	1.67	0.05	0.08	
	Seminole	0.044	0.67	1.86	1.25	
	Slaughter	0.129	1.96	1.90	3.72	
	Spraberry	0.158	2.40	0.16	0.38	
	Talco	0.032	0.49	3.00	1.47	
	Thompson	0.042	0.64	0.20	0.13	
	Tom O'Connor	0.101	1.54	0.16	0.25	
	TXL	0.065	0.99	0.16	0.16	
	Van	0.056	0.85	0.86	0.73	
	Ward-Estes N.	0.041	0.62	1.23	0.76	
	Wasson	0.116	1.76	1.01	1.78	
	Webster	0.128	1.95	0.21	0.41	
	West Ranch	0.048	0.73	0.90	0.66	
	Yates	0.775	11.78	1.50	17.67	
		6.579	100	0.63	62.96	0.63

Notes (1) Figures in parentheses are estimates.

(2) The above data are for the principal U.S. oil fields which contain about 70% of the proved reserves of the Continental U.S.

(3) Estimated reserves are for 1/1/70.

Source: 1971 International Petroleum Encyclopedia.

APPENDIX 3

TABLE 2
SUMMARY OF U.S. CRUDE OIL SULFUR CONTENT - PRINCIPAL OIL FIELDS

State or Region	Reserves, 1/1/70 10^9 bbls	%	Average Wt % S	S Contribution x 100
Appalachian	0.51	2.41	0.11	0.27
Arkansas	0.03	0.14	2.10	0.29
California	6.72	31.69	0.73	23.13
Colorado	0.16	0.75	0.65	0.49
Illinois	0.08	0.38	0.18	0.07
Kansas	0.19	0.90	0.52	0.47
La. onshore	3.33	15.71	0.24	3.77
La. offshore	1.39	6.56	0.30	1.97
Mississippi	0.11	0.52	2.13	1.11
Montana	0.25	1.18	0.90	1.06
New Mexico	0.17	0.80	0.68	0.54
Oklahoma	1.19	5.61	0.23	1.29
Texas	6.58	31.04	0.63	19.56
Utah	0.23	1.08	0.20	0.22
Wyoming	0.26	1.23	1.50	1.85
Continental U.S.	21.20	100	0.56	56.09
Alaska	20.36		0.99	

- Alternate Basis

State	Reserves* at end of 1970 10^9 bbls	%	Average Wt % S	S Contribution x 100
Texas	9.48	45.0	0.63	28.35
Louisiana	4.30	20.3	0.27	5.48
California	4.60	21.9	0.73	15.99
Oklahoma	0.54	2.5	0.23	0.58
Wyoming	0.53	2.5	1.50	3.75
New Mexico	0.36	1.7	0.68	1.16
Kansas	0.24	1.1	0.52	0.57
Others	1.07	5.0	0.54	2.70
	21.12	100	0.59	58.58

* In "giant" fields (ultimate reserves estimated to be more than 100 million barrels): Oil and Gas Journal, 1/22/71.

APPENDIX 3

TABLE 3
SUMMARY OF U.S. CRUDE OIL SULFUR CONTENT - ALL OIL FIELDS

	Crude Oil Reserves		NGL Reserves	
State	10^9 bbls	%	10^9 bbls	%
Texas	13.81	45.0	4.01	46.6
Louisiana	5.61	18.3	2.67	31.1
California	4.34	14.1	0.20	2.3
Oklahoma	1.39	4.5	0.45	5.2
Wyoming	1.10	3.6	0.08	1.0
New Mexico	0.96	2.8	0.60	7.0
Kansas	0.60	1.9	0.27	3.1
Others	3.00	9.8	0.32	3.7
Continental U.S.	30.71	100	8.60	100

Source: U.S. Bureau of Mines.

- Calculation of average S content:

State	% of Reserves	Av. Wt % S	S Contribution x 100
Texas	45.0	0.63	28.35
La. onshore	9.1	0.24	2.18
La. offshore	9.2	0.30	2.76
California	14.1	0.73	10.29
Oklahoma	4.5	0.23	1.04
Wyoming	3.6	1.50	5.40
New Mexico	2.8	0.68	1.90
Kansas	1.9	0.52	0.99
Others	9.8	0.54	5.29
Continental U.S.	100	0.58	58.20

- Total domestic reserves including Alaska:

	% of Reserves	Av. Wt % S	S Contribution
Lower 48	60	0.58	0.348
Alaska	40	0.99	0.396
	100	0.74	0.744

APPENDIX 3

TABLE 4
AVERAGE SULFUR CONTENT OF U.S. CRUDE OILS PRODUCED IN 1970

State	% of 1970 Production	Average Wt % S	S Contribution x 100
Texas	41.8	0.63	26.33
La. onshore	11.2	0.24	2.69
La. offshore	14.5	0.30	4.35
California	15.8	0.73	11.53
Oklahoma	5.0	0.23	1.15
Wyoming	3.7	1.50	5.55
New Mexico	2.4	0.68	1.63
Kansas	0.7	0.53	0.36
Others	4.9	0.54	2.65
Continental U.S.	100	0.56	56.24

Sources: U.S. Bureau of Mines and data from Table 3.

APPENDIX 3

TABLE 5
SULFUR CONTENT OF FOREIGN CRUDE OILS

- **CANADA**

Field	Wt % S	% of 1969 Production	S Contribution x 100	% of 1/1/70 Reserves	S Contribution x 100
Bonnie Glen	0.25	4.6	1.15	5.2	1.30
Fenn-Big Valley	0.71	2.8	1.99	2.5	1.78
Golden Spike	0.23	7.5	1.73	3.4	0.78
Judy Creek	0.25	6.8	1.70	7.0	1.75
Kaybob	0.04	1.7	0.07	5.9	0.24
Leduc-Woodbend	0.30	3.5	1.05	5.0	1.50
Mitsue	0.30	2.8	0.84	5.3	1.59
Pembina	0.42	18.8	7.90	19.5	8.19
Rainbow Lake	0.10	8.2	0.82	4.0	0.40
Redwater	0.42	7.6	3.19	6.6	2.77
Swan Hills	0.80	12.1	9.68	19.0	15.20
S. Swan Hills	0.80	4.8	3.84	5.4	4.32
Turner Valley	0.13	0.5	0.07	0.9	0.12
Wizard Lake	0.24	2.6	0.62	2.9	0.70
Zama Lake	0.25	2.9	0.73	3.3	0.83
Steelman	1.89	5.2	9.83	1.3	2.46
Weyburn	2.12	7.6	16.11	2.8	5.94
		100	61.32	100	49.87

Hence, av. S content of Canadian crude, based on:
- 1969 production 0.61 wt %
- reserves at 1/1/70 0.50 wt %

The S content of current production is higher than that of the estimated reserves because of the relatively higher production/reserves ratios for Saskatchewan crudes (Steelman and Weyburn).

APPENDIX 3

TABLE 5 (CONTINUED)
SULFUR CONTENT OF FOREIGN CRUDE OILS

- **MEXICO**

Field	Reserves 10^9 bbls	Reserves %	Wt % S	S Contribution x 100
Arenque	1.000	41.0	3.80	155.8
Ebano-Panuco	0.385	15.8	5.38	85.0
Naranjos-Cerro Azul	0.022	0.9	3.80	3.4
Poza Rica	1.028	42.3	1.70	71.9
	2.435	100	3.16	316.1

- **COLOMBIA**

La Cira	0.065		0.49	
Tibu	0.065		0.96	
Putamayo			0.49	(OGJ, 2/8/71)

- **PERU**

Concessiones Lima	0.29		0.12	
La Brea-Parinas	0.50		0.12	

- **VENEZUELA**

Bachaquero	2.74	2.41	2.62	63.14
Boscan	0.61	5.3	5.41	28.67
Cabimas	0.45	4.0	1.71	6.84
Lagunillas	3.12	27.6	2.54	70.10
Mene Grande	0.60	5.3	2.45	12.99
Oficina	0.57	5.0	0.61	3.05
Tia Juana	2.07	18.2	1.52	27.66
Quirequire	0.79	7.0	1.33	9.31
Mara	0.40	3.5	2.00	7.00
	11.35	100	2.29	228.76

- **IRAN**

Agha Jari	5.53	22.8	1.36	31.0
Ahwaz	8.56	35.4	1.66	58.8
Gach Saran	9.10	37.6	1.66	62.4
Haft Kel	1.01	4.2	1.12	4.7
	24.20	100	1.57	156.9

APPENDIX 3

TABLE 5 (CONTINUED)
SULFUR CONTENT OF FOREIGN CRUDE OILS

	Reserves			
Field	10^9 bbls	%	Wt % S	S Contribution x 100
• IRAQ				
Kirkuk	10.57		1.97	
• KUWAIT	68.00		2.53	
• SAUDI ARABIA				
Abqaiq	8.91	7.4	1.30	9.6
Dammam	5.00	4.2	1.54	6.5
Ghawar	69.60	58.0	1.66	96.3
Khursaniya	2.21	1.8	2.38	4.3
Qatif	8.74	7.3	2.57	18.8
Safaniya	25.57	21.3	3.03	64.5
	120.04	100	2.00	200.0
• NEAR EAST				
Abu Dhabi	18.00	5.4	1.3	7.02
Bahrein	0.34	0.1	1.2	0.12
Dubai	1.00	0.3	1.3	0.39
Iran	55.0	16.4	1.57	25.75
Iraq	27.50	8.2	1.97	16.15
Israel	negl.	--	--	--
Kuwait	68.00	20.3	2.53	51.36
Muscat, Oman	5.00	1.5	1.5	2.25
Neutral Zone	15.00	4.5	2.85	12.83
Qatar	5.50	1.6	1.35	2.16
Saudi Arabia	138.00	41.1	2.00	82.20
Syria	1.50	0.4	2.00	0.80
Turkey	0.65	0.2	2.00	0.40
	335.50	100	2.01	201.43

Near East on 1970 production basis: 1.95 wt % S.

APPENDIX 3

TABLE 5 (CONTINUED)
SULFUR CONTENT OF FOREIGN CRUDE OILS

- U.S.S.R.

Field	Reserves 10^9 bbls	Reserves %	Wt % S	S Contribution x 100
Romashkimo	14.31	39.2	1.70*	66.64
Samotlor	15.11	41.4	0.60	24.84
Uzen	4.86	13.3	0.20	2.66
Tuizmazy	2.24	6.1	1.50	9.15
	36.52	100	1.03**	103.29

* OGJ, 11/11/68.

** Other data suggest that the average may be approx. 1.25 wt % S.

- NORWAY

Ekofisk (North Sea)	0.16

- LIBYA 0.32

- NIGERIA 0.18 (OGJ, 2/8/71)

- MISCELLANEOUS ("Sulfur in Crude Oils Around the World", OGJ, 11/11/68)

Country	Field	Wt % S	
Iraq	Qaiyarah	7.31	
Indonesia	Tarakan	0.13	
	Kalimantan	0.07	
	Seria	0.05	
Neutral Zone	Wafra	3.12	
	Khafji	2.85	
Gabon	Manji	1.10	
Libya	Zelten	0.21	
Brazil	Bahia	0.04	
Algeria	Zarzaitine	0.05	
	Hassi Messaoud	0.16	
Bolivia	Camiri	0.02	
Saudi Arabia	Berri	1.18	(OGJ, 3/22/71)

APPENDIX 3

TABLE 6
SULFUR CONTENT OF FOREIGN CRUDE OILS BY GEOGRAPHICAL AREA

	Reserves			S Contribution
	10^9 bbls	%	Wt % S	x 100
• **ASIA/PACIFIC**				
Afghanistan	0.10	0.4	(0.50)	0.20
Australia	2.50	11.3	(0.20)	2.26
Brunei	0.65	2.9	0.05	0.15
Burma	0.20	0.9	0.20	0.18
India	0.72	3.2	(1.00)	3.20
Indonesia	18.00	80.8	0.10	8.08
Japan	0.03	0.1	(0.10)	0.01
New Zealand	0.03	0.1	(0.10)	0.01
Pakistan	0.05	0.2	(0.50)	0.10
Pakistan	0.05	0.2	(0.50)	0.10
Taiwan	0.02	0.1	(0.20)	0.02
	22.30	100	0.14	14.21
• **EUROPE**				
Austria	0.18	1.8	(0.2)	0.36
France	0.15	1.5	(0.2)	0.30
Italy	0.25	2.5	(1.5)	3.75
Netherlands	0.28	2.8	(0.2)	0.56
Norway	8.50	85.4	0.16	13.66
Spain	0.01	0.1	(0.5)	0.05
U.K.	0.01*	0.1	(0.2)	0.02
W. Germany	0.58	5.8	(0.3)	1.74
	9.96	100	0.20	20.44

- NEAR EAST — See Table 5
- CANADA — See Table 5
- U.S. — See Table 3

Note: Figures in parentheses are estimates.

* Does not include North Sea discoveries which, however, are expected to be similar in S content to Norwegian reserves in same area.

APPENDIX 3

TABLE 6 (CONTINUED)
SULFUR CONTENT OF FOREIGN CRUDE OILS BY GEOGRAPHICAL AREA

	Reserves			S Contribution
	10^9 bbls	%	Wt % S	x 100
• **AFRICA**				
Algeria	30.00	42.3	0.16	6.77
Angola	0.65	0.9	(0.2)	0.18
Egypt	5.00	7.1	(1.0)	7.10
Gabon	0.50	0.7	(0.2)	0.14
Dahomey	0.02	--	--	--
Libya	29.20	41.2	0.3	12.36
Nigeria	5.00	7.1	0.18	1.28
Tunisia	0.50	0.7	0.2	0.14
	70.87	100	0.28	27.98
• **LATIN AMERICA**				
Argentina	4.00	13.1	(0.2)	2.62
Bolivia	0.25	0.8	0.02	0.02
Brazil	1.00	3.3	0.04	0.13
Chile	0.13	0.4	0.2	0.01
Colombia	1.75	5.7	0.75	4.28
Ecuador	0.50	1.6	0.5	0.80
Mexico	8.00	2.62	3.16	82.79
Peru	0.27	0.9	0.1	0.09
Trinidad	0.60	2.0	2.0	4.0
Venezuela	14.00	46.0	2.0	92.00
	30.50	100	1.87	186.7
• **COMMUNIST BLOC**				
Albania	0.02	negl.	--	--
Bulgaria	0.02	negl.	--	--
China	19.60	25.9	(1.6)	41.44
Czechoslovakia	0.01	negl.	--	--
E. Germany	0.01	negl.	--	--
Hungary	0.05	0.1	(0.2)	0.02
Poland	0.02	negl.	--	--
Romania	0.75	1.0	(0.2)	0.20
U.S.S.R.	55.00	72.7	(1.25)*	90.88
Yugoslavia	0.24	0.3	0.2	0.06
	75.72	100	1.33	132.6

* Export crude averages about 1.5 wt % S.

APPENDIX 3

TABLE 7

WORLD SUMMARIES OF CRUDE OIL SULFUR CONTENT

- WORLD

	Reserves Basis			1970 Production Basis	
	Reserves				
Area	10^9 bbls	%	Average Wt% S	% of 1970 Production	Average Wt% S
Near East	335.50	55.6	2.01	30.7	1.95
Asia/Pacific	22.30	3.7	0.14	3.0	0.14
Europe	9.96	1.7	0.20	0.8	0.20
Africa	70.87	11.7	0.28	13.3	0.28
Canada	8.62	1.4	0.50	2.9	0.61
Latin America	30.50	5.1	1.87	11.3	1.87
U.S.	50.00	8.3	0.74	21.2	0.56
Com. Bloc	75.72	12.5	1.33	16.8	1.33
	603.47	100	1.49	100	1.21

- FREE WORLD EX U.S.

	477.75	79.2	1.59	62.0	1.40

- FREE WORLD

	527.75	87.5	1.56	83.2	1.19

APPENDIX 3

TABLE 8
ADDITIONAL REFERENCES TO SULFUR CONTENT OF PETROLEUM

(i) Oil and Gas Journal, 9/6/71, page 108, "Literature on Sulfur Content of World Crudes". The following references, all by W. L. Nelson, relate to "Questions on Technology" that involve S content:

1. "Sulfur Content of Oils Throughout the World," Feb. 3, 1967, p. 122.
2. "Sulfur in Straight-run Residues (boiling above 700°F.)," Sept. 22, 1967, p. 108.
3. "How much Sulfur in Straight-run Residuals," Oct. 23, 1967, p. 98.
4. "Can Sulfur be Reduced by Visbreaking," Nov. 6, 1967, p. 96.
5. "Sulfur Distribution in Extreme or Freak Crude Oils," Dec. 4, 1967, p. 92.
6. "What is Composition of High-sulfur Resid," May 20, 1968, p. 89.
7. "Sulfur in Crude Oils Around the World," Nov. 11, 1968, p. 96.*
8. "Here's more on Effects of Composition and Sulfur on the Shape of Crude-oil (distillation) Curves," Feb. 10, 1969, p. 79.
9. "Stability, Sourness of Crude related to Mercaptans and Hydrogen Sulfide (weight percentages for over 147 crude analyses)," May 19, 1969, p. 100.
10. "Revised Sulfur and Sourness Penalties (for crude oil evaluations) June 2, 1969, p. 96.
11. "How Different are (new) Sulfur Penalties," Nov. 24, 1969, p. 113.
12. "Sulfur Content of (over 180) U.S. Crude Oils," Aug. 17, 1970, p. 78.
13. "More on Sulfur Content of Crude Oils of the U.S.," Aug. 24, 1970, p. 65.

(ii) Petroleum Refiner, May 1957, pp. 257-260, "Domestic Crudes Contain Less Sulfur; E. M. Shelton, C. M. McKinney and O. C. Blade.

(iii) API preprint, 5/29/59, "Keys to the Mystery of Crude Oil"; H. M. Smith, H. N. Dunning, H. T. Rall and J. S. Ball.

*This reference is particularly useful.

APPENDIX 3

TABLE 9
WORLDWIDE RESERVES OF NATURAL GAS

• NEAR EAST	Reserves in Million Metric Tons*
Iran	4849
Saudi Arabia	1133
Kuwait	657
Iraq	431
Abu Dhabi	227
Qatar	227
Other	158
	7682
• ASIA/PACIFIC	
Afghanistan	116
Australia	286**
Brunei	113
Burma	2
India	45
Indonesia	52
Japan	14
New Zealand	11
Pakistan	454
Taiwan	20
	1113
• CANADA	1305
• U.S.	6234

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* Converted from cubic feet on the basis of 22.66 million SCF per metric ton.

** OGJ, 8/16/71, page 48, suggests a higher figure (313 million MT).

Principal Source: 1971 International Petroleum Encyclopedia.

APPENDIX 3
TABLE 9 Continued

- EUROPE

Netherlands	1865
U.K.	793
W. Germany	270
France	163
Italy	143
Others	77
	3311

- Africa

Algeria	2267
Libya	680
Nigeria	113
Egypt	113
Gabon	113
Others	59
	3345

- LATIN AMERICA

Venezuela	613
Mexico	272
Argentina	199
Bolivia	113
Brazil	113
Trinidad	113
Peru	68
Colombia	68
Others	61
	1620

- COMMUNIST BLOC

Yugoslavia	79
Albania	7
Bulgaria	23
China	82
Czechoslovakia	11
E. Germany	11
Hungary	156
Poland	7
Romania	136
U.S.S.R.	11985
	12497

APPENDIX 3

TABLE 10
WORLD SUMMARY OF NATURAL GAS RESERVES

	Reserves in Billion Metric Tons	%
• WORLD		
Near East	7.68	20.7
Asia/Pacific	1.11	3.0
Europe	3.31	8.9
Africa	3.35	9.0
Canada	1.31	3.5
Latin America	1.62	4.4
U.S.	6.23	16.8
Com. Bloc.	12.50	33.7
	37.11	100
• WORLD ex U.S.	30.88	83.2
• FREE WORLD	24.61	66.3
• FREE WORLD ex U.S.	18.38	49.5

APPENDIX 3

TABLE 11
SULFUR CONTENT OF WORLD NATURAL GAS RESERVES

	Million Metric Tons of Sulfur	%
• WORLD		
Near East	22.5	6.2
Asia/Pacific	0.1	negl.
Europe	75.3	20.8
Africa	15.9	4.4
Canada	146.5	40.4
Latin America	negl.	negl.
U.S.	25.4	7.0
Com. Bloc.	76.8	21.2
	362.5	100
• WORLD ex U.S.	337.1	93.0
• FREE WORLD	285.7	78.8
• FREE WORLD ex U.S.	260.3	71.8

World Average S Content of Natural Gas = 0.70 wt.%

APPENDIX 3

TABLE 12
SULFUR CONTENT OF NATURAL GAS

- The S content of many W. Canadian gas fields is given on page 32 of "The Economics of one Sulfur Industry"; Jared E. Hazleton, RFF, 1970.

- Oil and Gas Journal, 3/29/71, page 92 presents information on gas treatment plants to be constructed in the U.S.S.R., France, Austria, Italy, Kuwait, and W. Germany. More details concerning Russian projects are given on page 121.

- Canadian Petroleum, May 1971, page 24 lists recoverable reserves of sulfur contained in U.S. Canadian natural gas:

	1000 Long Tons	
	1969	1970
Alberta	123,769	141,569
Saskatchewan	21	22
British Columbia	2,722	2,598
Total	126,512	144,189

- Canadian Petroleum, June 1971, page 39 at seq. record the "9th Census of Canadian Gas Processing Plants" which provides considerable information on S recovery capacity.

- Note that the following estimates give S content on a wt.% basis as discussed in the text (rather than on a conventional mol % H_2S basis).

	Average wt.% S
Canadian reserves	11.1
Canadian 1970 production	10.3
USSR	0.64
Iran	0.315
U.S.	0.15 (excluding Mississippi)
France	22.9 (OGJ, 10/19/70)
W. Germany	10.0
Netherlands	NIL
North Sea	NIL
Australia	0.01
Libya	2

APPENDIX 3

TABLE 13

SULFUR CONTENT OF U.S. COAL

	Average 106 BTU per MT	Average Wt% S	Wt% S Corr. to 28.9 x 10^6 BTU	Reserves in 10^9 MT Corr. to 28.9 x 10^6 BTU	10^9 MT of S
• **Eastern States**					
Illinois	28.9	3.5	3.5	123	4.31
W. Virginia	28.9	1.5	1.5	92	1.38
Pennsylvania	28.5	2.3	2.3	72	1.66
Kentucky	28.9	2.4	2.4	61	1.46
Ohio	28.9	3.4	3.4	36	1.22
Indiana	28.9	2.8	2.8	28	0.78
Missouri	28.9	3.9	3.9	20	0.78
Kansas	28.9	3.4	3.4	14	0.48
Alabama	28.9	1.5	1.5	10	0.15
Texas	23.6	2.3	2.8	8	0.22
Virginia	28.9	0.9	0.9	8	0.07
Others	27.1	2.9	3.1	27	0.84
			2.67	499	13.35
• **Western States**					
N. Dakota	14.8	0.4	0.78	163	1.27
Montana	18.3	0.7	1.10	127	1.40
Wyoming	22.0	0.8	1.05	81	0.85
Colorado	27.4	0.4	0.42	69	0.29
New Mexico	21.7	0.7	0.93	41	0.38
Utah	28.9	1.3	1.30	27	0.35
			0.89	508	4.54
• **Alaska**	22.1	0.7	0.92	89	0.82
• U.S. Total	--	--	1.71	1096	18.71

Source: Calculations based on page 43 et seq. of "The Economy, Energy, and the Environment," GPO, 9/1/70.

APPENDIX 3

TABLE 14
SULFUR CONTENT OF FOREIGN COAL

- U.S. Bureau of Mines Bulletin No. 512, "Analysis of Foreign Coals", R. E. Morgan and J. F. Barkley, present S content and other data from which it is possible to calculate the following average S contents:

	wt.% S		wt.% S
Australia	0.60	Belgium	0.55
New Zealand	2.33	France	0.83
South Africa	1.40	Germany	0.88
India	0.57	Greece	2.33
Indonesia	0.60	Ireland	1.53
Indo China	0.50	Italy	0.95
Japan	0.94	Netherlands	1.33
Malaysia	0.38	Sardinia	8.2
N. Korea	0.73	Spain	1.21
Pakistan	5.5	U.K.	1.14
Philippines	1.00		
Canada	0.68	Bulgaria	2.20
		Czechoslovahia	1.60
Argentina	0.90	Romania	0.65
Brazil	4.60	U.S.S.R.	1.10
Chile	1.46	China	0.78
Mexico	0.46		

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TABLE 15
WORLDWIDE SULFUR CONTENT OF COAL

	Average S Content wt.%	Billion MT of S in Reserves
W. Europe	0.98	4.77
Canada	0.68	0.61
Japan	0.94	0.15
Latin America	1.96	0.06
Africa	1.40	2.89
Asia/Pacific (excl. Japan)	0.59	0.70
Free World ex U.S.	0.93	9.18
E. Europe	0.91	3.35
U.S.S.R.	1.10	13.20
Communist Asia	0.78	7.94
Communist Bloc.	0.95	24.59
U.S.	1.71*	18.71*
U.S.	1.56	18.71
World	1.12	55.77

*Corrected for heat content to 28.9 x 10^6 BTU/MT. When the foreign coals are similarly corrected for heat content, their calculated S content becomes:

	wt.% S (corrected)
Free World ex U.S.	1.00
Communist Bloc.	1.37
U.S. (see above)	1.71
World	1.46

APPENDIX 4

SULFUR SUPPLY FORECAST

A.4.1. Frasch Sulfur

The U.S. Frasch sulfur industry has produced about 210 million LT of sulfur since its beginning in 1894. About 58 million LT came from domes that are now shut down and, for the most part, depleted. The balance of the production came from domes that are still in operation. Details are given in Tables 1 and 2.

In recent years, U.S. Frasch production has been of the order of 7 million LT/yr. The question arises as to how long this rate of production could be maintained before remaining reserves would be exhausted. However, production has declined somewhat in view of growing supplies of recovered sulfur. In consequence, it is reasonable to examine the reserves question on the basis of (long range average) annual production of 6 million LT/yr. or less. This is not a production forecast for U.S. Frasch sulfur, rather it is a way of calculating what a reasonable upper level of production may be.

In Table 3 it is estimated that remaining reserves exceed 200 million LT in currently worked deposits. This quantity should be sufficient for maintenance of significant production until close to the end of the forecast period (2020). Additional, but much smaller, reserves are potentially available in some of the shut down domes (e.g. Caminada). However, such domes would be reactivated only at price levels appreciably higher than are likely for some time. Nevertheless, the reserves in these "high cost" domes, when added to the estimated 210 million LT in currently worked deposits, make it reasonable to assume continuing potential availability of Frasch sulfur. Actual availability will depend on whether the Frasch producers are able to obtain economic returns for their product.

Much the same picture emerges for Mexican Frasch sulfur when reserves are compared with reasonable production levels.

It is entirely possible that additional deposits of sulfur exist in _offshore_ salt domes. However, production from such domes (if they exist) would surely be more expensive than from the currently worked deposits. Hence, no offshore exploration for additional _U.S._ deposits of sulfur is likely without substantial increases in sulfur prices. In addition, the latter may be a moving target since certain costs (e.g. labor, fuel) of Frasch production are bound to increase with time. In consequence, the price required to induce _new_, offshore production of Frasch sulfur will increase with time.

A.4.2. Petroleum

A state by state listing of petroleum refining capacity is given in Table 4. Note is taken of crude oil charging capacity as well as hydrotreating and alkylation plants (that represent sources of sulfur supply and demand respectively).

More than 60 plants recover elemental S from refinery gas (i.e., streams containing H_2S.) However, not all of the S values from petroleum refining are recovered in elemental form. There are at least 17 plants that product sulfuric acid from refinery H_2S streams. In addition, there are 34 plants that product fresh acid from acid sludge or spent acid (most of which is obtained from petroleum refining operations, particularly aklylation). Fifteen out of eighteen plants that make acid from H_2S also burn sludge (i.e., these 15 plants are included in the total of 34). This will be discussed further.

Manufacture of acid from sludge may be considered as a recycle operation that does nct contribute to the net supply of sulfur. On the other hand, recovery of either acid or elemental S from H_2S does contribute to net supply.

A regionalized, state by state, listing of refinery gas sulfur plants is given in Table 5 . The capacity statistics are summarized in Table 6 . It is worth noting that chemical companies operated 11 of the recovery plants having a combined capacity amounting to 28% of the total.

Although capacity totals 1.5 million LT, actual recovery in 1970 was approximately 0.9 million LT. Capacity will increase appreciably during the next few years and its % utilization may increase also. The biggest increases are likely to occur in California, Texas, N.J., Delaware and Illinois.

There are 7 states for which hydrotreating capacity is reported but without any S recovery capacity being shown in Table 6:

State	MB/SD	% of Total U.S. Hydrotreating Capacity
W. Va.	4.0	0.1
Wis.	9.2	0.2
Ala.	5.5	0.1
N.D.	9.0	0.2
Wash.	100.2	2.3
Utah	14.0	0.3
Okla.	82.5	1.9
	224.4	5.1

However, H_2S from Washington's Anacortes refinery is converted to sulfuric acid rather than being recovered as elemental S. Furthermore, North Dakota's Mandan refinery uses hydrogen to saturate olefins rather than for desulfurization, and the same is true for part of the hydro capacity shown for Utah. When these cases are taken into account, the above list shrinks as follows:

State	MB/SD	% of Total
W. Va.	4.0	0.1
Wis.	9.2	0.2
Ala.	5.5	0.1
Utah	8.5	0.2
Okla.	82.5	1.9
	109.7	2.5

70% of the 109.7 MB/SD is for hydrotreating of cat. reformer feed and other naphthas. The other 30% of the hydrotreating capacity is entirely for distillates, including lube oil "polishing" (to improve color). None of these operations would generate quantities of H_2S that, if recovered as elemental S, would add significantly to U.S. supplies of sulfur. Considering both the nature of the hydrofining operations and the capacity involved, it is estimated that a maximum of 7,000 LT/yr* of S is not being recovered from the pertinent hydrofiner tail gases. However, there are also other individual refineries in states which do have S recovery plants that use distillate hydrotreating but have not yet arranged for tail gas treatment. In total, it is possible that a maximum of 15,000 LT/yr. of S is not being recovered from hydrofiner tail gases in all U.S. refineries.**

Recognizing that lack of S recovery (associated with hydrofining capacity) could cause air pollution in individual cases, it is also clear that complete recovery would result in a negligible increase in total U.S. sulfur supplies. From the latter standpoint, the major factor will be the expansion of petroleum desulfurization capacity that, without future exception, will be tied-in either with (elemental) S recovery plants or with utilization of H_2S or SO_2 streams to produce sulfuric acid.

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* In 1970 actual recovery of elemental S from refinery gases was about 900,000 LT. The 7,000 LT estimate is obtained by multiplying the actual recovery first by 2.5% and then by a factor of 0.3 to adjust for the type of hydrofining involved.

** A much larger quantity of S in the form of SO_x is emitted from petroleum refineries, and comes from the combustion of the fuel used to generate process heat. This, however, is not the point at issue.

In the future, expansion of petroleum refining capacity is expected to follow trends in population growth while retaining the basic geographical pattern already established. The latter is influenced by logistics, in particular by the location of domestic crude oil resources and by the major points of entry of imported petroleum (by pipeline and tanker). Accordingly, the population distribution projections in Table 7 were used to normalize the projected distribution of refining capacity in Table 8. The latter was then used in conjunction with the projections of sulfur in the U. S. petroleum supply (Table 9) to obtain regionalized estimates of sulfur recovery from domestic refineries (Table 10). In further calculations, a simplifying assumption was made that sulfur recovery from refineries will be entirely in the form of elemental S. In practice, recovery as acid will continue but is very unlikely to show the growth expected for elemental S. When H_2S is available in large amounts (from hydrodesulfurization) it will generally be more convenient to convert all of it to elemental S rather than part to acid and part to elemental S. Local outlet for acid would, of course, place an upper limit on production of acid thereby preventing conversion of all of the S values recovered in (most) individual refineries to acid.

As noted in the second paragraph of this section, 34 acid plants use sludge or spent acid as feed, and 15 of these plants also feed H_2S. Seven of these combined operations are integral parts of petroleum refineries. Most of the others are operated by chemical companies, e.g., Stauffer, as a service to petroleum refineries.

Details of the plants and their locations are given in Table 11. The plant capacities are not good indicators of new acid supply in that spent acid recovery is essentially a recycle operation. Even where H_2S is fed, most of the plants also feed elemental S, thereby obscuring the acid capacity that is directly associated with recovered H_2S. However, it is estimated that, in 1970, approximately 200,000 LT of S in the form of acid were recovered from refinery streams. Thus, the toal recovery from petroleum refining was about 1.1 million LT of S equivalent.

A.4.3 Natural Gas

A.4.3.1 U.S. Natural Gas

Of the approximately 60 plants that recover elemental S from sour natural gas, 40 are in Texas. These plants represent 80% of current U.S. capacity of about 1.1 million LT/yr. In 1970, actual recovery is estimated to have been 0.66 million LT. However, a very significant addition to capacity, 0.4 million LT/yr., is soon to be brought on stream at Jackson, Miss. This Shell plant may be doubled in size before 1980. Thus, there will be a substantial change to the capacity summarized in Table 12.

An even greater boost to supply will occur when coal-to-gas conversion comes to commercial fruition. This is likely to occur in Regions No. 4 and 10 of the Sulfur Model, covering respectively the E.N. Central and Mountain States.

For the purpose of the computer calculations, it has been assumed that the incremental demand for gas after 1985 will be satisfied by coal conversion. It is recognized that some sulfur will be recovered from coal gasification before 1985. However, it is not expected that such recovery will have a significant impact on total U.S. sulfur supplies until after 1985. These projections are included in Table 13.

The jump in recovery in Region No. 11 between 1970 and 1975 is due to the inclusion of new Mississippi production. Because of its proximity to the Gulf coast (and to petrochemical demand in Louisiana), new production from the Florida/Alabama panhandle is also included in Region No. 11.

It is possible that domestic natural gas production will begin a slow rate of decline before 1985. However, this would not necessarily mean that sulfur recovery would decline. If certain "tight" gas reservoirs are stimulated with nuclear explosives, it is probable that S recovery would increase as a percentage of gas processed. Last year, S recovered from natural gas was equivalent to about 7% of the total U.S. demand for S in all forms. By 1975 the percentage should approximate 10, and may reach 12% by 1980 due to the Mississippi gas. Before 1985, however, increased S demand is not likely to be matched by increased supplies from natural gas, i.e., the % contribution to total U.S. supply is expected to decline.

Although the sulfur expected to be recovered from gasified coal looms large in the later time periods in Table 13, it must be considered that sulfur is likely to be recovered whether the coal is burned as a solid or is first converted into a gaseous (or liquid) form. Only a third of current gas demand is accounted for by the Residential and Commercial Sector; almost two thirds is consumed by Industry and Electric Utilities. Thus, sulfur recovery from coal will be influenced primarily by total energy demand in absolute terms and by how much of this demand is supplied by coal. The form in which coal is used will be of lesser importance to estimates of future S supply. Nevertheless, it is recognized that coal gasification would lead to recovery of elemental S while direct combustion of coal might yield elemental S, acid, or a throwaway by-product. In spite of this, the direct burning capacity already in place, together with what will be installed up till the time that coal conversion becomes a commercial reality, mean that the Model is not very sensitive to coal gasification assumptions until after the year 2000.

Projections of the combined recovery of elemental S from petroleum, natural and synthetic gas are given in Table 14.

A 4.3.2 Canadian Natural Gas

The recovery of elemental sulfur from sour natural gas in Western Canada is generally regarded as the single most important factor in the current surplus of sulfur supply over demand.

Details of the W. Canadian S recovery plants are given in Table 15, which also includes capacity that is expected to come on stream during 1971.

It should be pointed out that the plant cost refers to all facilities for gathering, dehydration, and fractionation of natural gas liquids, as well as separation of H_2S and recovery of elemental S. On the average, the capital invested for S removal and recovery would approximate \$3/LT amortized over a 20 year period. Operating costs, in the larger S recovery plants, are believed to be less than \$2/LT of S recovered. Thus, the out of pocket cost for sulfur recovery in W. Canada is believed to average less than \$5/LT. This figure does not include a return on investment since the current purpose of the plants is not to recover sulfur but to make natural gas saleable.

Another way of looking at the economics of S recovery would be to charge the cost of separating H_2S to the natural gas, and to charge the Claus conversion of H_2S to elemental S to the latter. This approach also leads to costs of about \$5/LT after allowing for an R.O.I. on the Claus conversion.

Ex plant prices for elemental S as low as \$6/LT have been reported. Currently, however, the price quoted for delivery to the U.S. is about \$9/LT. The implication is that export prices, for other than U.S. destinations, are somewhat lower.

Although it would appear that the net-back for W. Canadian sulfur is adequately covering production costs, it must be recognized that only a fraction of total production is being sold and the remainder is being stockpiled. It is very difficult to assign a value to stockpiled S since it may be an appreciable time before the Canadian inventory can be sold. Thus, it may be that sulfur recovery currently represents a small charge against the production of natural gas.*

It is of interest to review the sour gas projects that are expected to be completed this year:

Location	MM CFD Raw Gas	 Product Gas	Sulfur Capacity LT/D
Ram River	220	150	2032
Lone Pine Creek	30	22	130
Kaybob South	445	284	2850
Strachan	250	201	840
Quirk Creek	90	68	240
Redwater	7	5	7

With the exception of the small Redwater plant, the new capacity is intended to handle very sour gas. Furthermore, two of the plants are the largest in Canada except for Shell's Waterton facility. Thus, it appears that the price now obtainable for natural gas is sufficient to offset the cost of sulfur removal, even though the raw gas from Kaybob South has a sulfur content of about 20 mol. % and that from Ram River about 30 mol. %.

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* The theoretical alternative of separating H_2S and reinjecting it into the producing formation (instead of recovering S by the Claus process) is not considered attractive since the concentration of H_2S in the gas produced would gradually increase.

It is of interest to examine the total processing costs of Canadian sour gas in order to obtain an idea of the way in which cost varies with H_2S content, plant size, etc. In this way, it is possible to estimate the total cost of H_2S removal and S recovery as a hypothetical charge against the treated gas product. Data are presented in Table 16 and may be summarized:

	(A)	(B)	(C)
Mol.% H_2S	10	20	35
Costs, cents/MCF of Product Gas			
- Gathering System	3.0	3.6	5.7
- H_2S Removal + S Recovery	6.1	11.0	26.8
- Total Cost*	9.1	14.6	32.5

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* Including 10%/yr straight line depreciation, but excluding R.O.I.

Last October, the Federal Power Commission authorized the Tennessee Gas Pipeline Company to import Canadian natural gas, paying Trans-Canada Pipelines Ltd. 42¢/MCF. The price received by Canadian gas producers would, of course, be significantly less than 42¢/MCF*. On this basis, the total cost of 36.5¢/MCF for production of saleable gas from 35 mol.% H_2S gas raises the question of the economic feasibility of Case (C). If a sulfur credit of $6/LT or more is assumed, the net cost of gas production would fall to 15.9¢/MCF or less. On the other hand, if only part of the sulfur recovered could be sold, such that the effective sulfur credit were to be only $3/LT, then the gas cost would be 24.2¢/MCF. The latter figure would not provide an adequate return on the operation. Nevertheless, gas with H_2S contents of 35 mol.% and even higher are being produced. In fact, the Ram River project, to be completed this year, is essentially in this category.

A partial explanation follows from Table17 which indicates the effect of plant size. The 50 MMCFD raw gas capacity chosen for the calculations in Table 7 is small compared with the average size of 163 MMCFD for the 44 plants listed in Table 6. Only 10 of the plants in this table had capacities of 50 MMCFD or less. Together, these plants amounted to only 3.8% of the industry's estimated capacity at the end of the year.

What is happening now is that very sour gas is tending to be processed in very large plants. The cost of the sulfur recovery step (Claus process or equivalent) is easily covered by the effective sulfur credit (i.e. the credit for sulfur actually sold). Other processing costs, for gathering and H_2S separation, are being charged against the treated gas produced. Such costs will vary greatly, but for large plants will be much less than the 15.9¢/MCF or 24.2¢/MCF cited above.

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*It is believed to be slightly above 20¢/MCF.

At the end of 1970 the cumulative production of elemental S in Western Canada was 22.7 million LT. At the same time, the S recoverable from remaining proved reserves of sour gas was estimated to be 144.2 million LT.* This is equivalent to about 35 years production at the 1970 rate of 4.1 million LT. However, Canadian gas production is rising and, by 1980, will probably be double the rate last year. During this period S recovery will be roughly proportional to total gas production. Hence, by 1980 annual S recovery in W. Canada is likely to approximate 8 million LT. The build up of Western Canadian S recovery capacity is recorded in Table 18. Consideration of the reserves of sour gas, and of the fact that very large discoveries of sweet gas have been made in the Canadian arctic, lead to the conclusion that sulfur production will peak about 1980 and will be declining by 1985.

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* An increase of 17.7 million LT over the proved reserves at the end of 1969.

A 4 4 Smelters and Other Sources

A 4.4.1 U.S. Smelters

The former National Air Pollution Control Administration estimated that, without abatement, U.S. smelters could generate sulfur values on the following schedule:

	Sulfur Equivalent	
	10^6 ST	10^6 LT
1970	4.0	3.6
1980	5.3	3.7
1990	7.1	6.3
2000	9.6	8.6

The above schedule is equivalent to the following compound annual growth rates:

	% Per Year
1970-1980	2.9
1980-1990	3.0
1990-2000	3.1
1970-2000	3.0

Somewhat more recent estimates, based on a study by Arthur G. McKee and Co. and supplemented with Bureau of Mines data and monthly production statistics reported by the Department of Commerce*, suggest that the total quantity of S values generated by Cu/Pb/Zn smelters approximated 3.2 million LT in 1970. If the latter quantity is taken as a base and projected to grow at an average rate of 3%/year to the year 2000, 2.5%/year to 2010, and 2.0%/year to 2020, the following S potential results (million LT of S equivalents):

1970	1975	1980	1985	1990	2000	2010	2020
3.2	3.7	4.2	4.9	5.7	7.7	9.8	12.1

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* "Environmental Science and Technology", July 1970.
U. S. Bureau of Mines "Minerals Handbook".
U. S. Dept. of Commerce "Survey of Current Business".

The overall % recovery approximated 37% last year, i.e. 1.1-1.2 million LT of S values were recovered from U.S smelters Because of air pollution control regulations, recovery is expected to reach about 85% in 1975 (when control systems will be almost, but not completely, installed) and 90% by 1980. The latter level is expected to be maintained in subsequent years. On this basis, the quantity of S recovered would be:

1970	1975	1980	1985	1990	2000	2010	2020
1.1-1.2	3.1	3.8	4.4	5.1	6.9	8.8	10.8

It is probable that only a part of the recovery will be in useful form. The remainder, particularly from Western copper smelters, is likely to be in the form of waste gypsum and, perhaps, sodium sulfate.* For the purpose of discussion, it will be assumed, arbitrarily, that 40% of incremental recovery (over 1970 levels) will be in useful form. These projections are summarized in Table 19.

The projections may also be made, separately, for copper, lead and zinc. The primary production of these metals is expected to have the growth rates shown in Table 20. The latter were used to derive the estimates of recovered S values shown in Table 21. In aggregate, the totals are similar to those in Table 19 However, the advantage of the separate estimates for copper, lead and zinc smelters is that the figures may be regionalized for the purpose of incorporation into regional supply/demand balances

A listing of U.S. sulfuric acid plants that utilize smelter gases is given in Table 22. The total capacity of 6.33 million ST/yr. of acid is equivalent to 1.85 million LT/yr. of elemental S, and may be compared with an estimated recovery of 1.1 - 1.2 million LT or S equivalent from smelters in 1970. A number of the plants listed use elemental S as well as smelter gases.

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* "The Impact of Air Pollution on the Copper Industry", Fluor-Utah. April 1971

The information in the preceding tables was used to project quantities of S that will be generated by all types of U.S. smelters. These projections, regionalized for the computer model, are given in Table 23 The figures refer only to generation of S values not to amounts that may be recovered.

Theoretically, S values from smelters may be recovered as ammonium sulfate, elemental S, waste gypsum, sulfuric acid etc. In general, recovery as acid is probable provided that local outlet is available. In fact, markets for acid are likely to be developed over a period of years (as has occured in the area supplied by the Tennessee Corporation). The time needed for market development has been factored into the projections made in Table 24. As shown in the footnotes, what, in effect, has been projected is the minimum percentage of regional S demand that will be supplied in elemental form. The figures in the Table are estimates of maximum possible penetration of regional markets with acid at different times in the future. Actual penetration may be appreciably below the figures shown.

A.4.4.2 Canadian Smelters

A study by the Canadian National Advisory Committee on Mining and Metallurgical Research, has estimated that Canadian Smelting operations generated about 2.75 million tons of S values in 1969. Approximately 0.55 million tons of this total was recovered, almost entirely in the form of acid.

The study covered 77 mine and metallurgical sites across Canada:

Yukon	3	Ont.	24
N.W.T.	4	Que.	14
B.C.	13	N.B.	2
Alta	4	N.S.	2
Sask.	4	Nfd. & Lab.	5
Man.	2		

The above includes metallurgical operations of all kinds. However, 95% of the SO_x emissions are from copper and nickel smelters.

Air pollution control regulations will require a progressive reduction in the percentage of SO_x emitted from smelters up to a level of 90% in 1979.

Some smelting operations will switch from pyrometallurgy to hydrometallurgy in new plants. Once consequence of this switch will be that S values will be recovered in the form of ammonium sulfate. However, this change is not likely to be applied at existing smelters.

There are plans for significant increases in production of sulfuric acid. However, the ability of markets (reachable at economic transportation cost) to absorb incremental acid production is recognized to be limited. In consequence, some smelters will recover elemental sulfur while others may go to neutralization with lime (particularly for more dilute SO_2 streams).

The above and certain other information was used to make the projections in Table 25.

A.4.5 Total U.S. Supplies

The projections of U.S. sulfur supplies, on a regionalized basis, are considered first in terms of the sum of what is expected to be available before abatement S and Frasch S are taken into account. Table 26 indicates that the total supply from natural gas, coal gasification, petroleum desulfurization, smelters, etc. is expected to be:

	1975	1985	2000	2020
Million LT	4.8	7.8	14.7	30.1

When various degrees of recovery of abatement sulfur in useful form are added, the effect on regional sulfur supply is shown in Tables 27-33. The top portion of each table has a column headed "Regional Supply," with a footnote that this is before inclusion of abatement S in useful form and Frasch S (in Region No. 11). Five different quantities of abatement S in useful form are shown in the remaining columns in the top part of each table. The effect on total regional supply, excluding Frasch S, is shown in the bottom half of each table.

The assumptions underlying the quantities of abatement S in useful form are indicated in Table 34. Column (a) in this table makes the assumption that 1970 levels of SO_x emissions would be maintained in terms of the total quantity emitted. It will be appreciated that this would represent a decrease in the average concentration of SO_x emitted from stationary sources (assuming that the quantity of coal burned by electric utilities increases). Thus, "nil" in sub-column "R" is equivalent to assuming that only the increment in SO_x emissions over 1970 levels will be abated. The other figures in sub-column "R", e.g., -20, signify the % reduction of total SO_x emitted from 1970 levels.

For a given quantity of abatement S in useful form, it is apparent that the percentage recovered in useful form must decrease as the level of recovery increases. For example, in 1975, Case (2), 0.55 million LT of S in useful form could be recovered at 1970 emission levels with 50% in useful form or with a 40% reduction from 1970 levels with only 10% in useful form. As time progresses, the increment in potential SO_x emissions over 1970 levels becomes larger in proportion to the 1970 level itself. This means that percentage reduction below 1970 levels has a relatively lesser effect on the quantity of abatement S recovered (in any form). However, the percentage recovered in useful form has an increasingly important effect on total supplies of sulfur.

In Table 35 the same assumptions concerning abatement control are translated on the basis of the average sulfur content of utility coal that would be needed to achieve the equivalent levels of SO_x emissions without any sulfur recovery systems. Although these average sulfur content figures are hypothetical, they are not without meaning. With a knowledge of the natural sulfur contents of U.S. coals (Appendix 3), it is at once apparent that the higher levels of control of SO_x emissions, particularly in later years, are not possible without abatement systems or coal pre-treatment processes that would lower S content appreciably. For example, without these alternatives (i.e., abatement system or coal pre-treatment), utility coal would have to have an average S content of about 1.06 wt % in the year 2000--less than half the average S content of today's utility coal.

A.4.6 U.S. Regionalized Supply/Demand Balances

Demand projections are discussed in Appendix 5. However, the results of these projections are summarized in Tables 36-42, in the left-hand column of each table, so that the "balance" or net regional demand may be calculated in conjunction with the regionalized supply projections given in Tables 27-33.

The top part of each table is concerned with the base cases of demand. The lower part or parts indicate the effects of "parametric demand increases" on the regional balances. For 1975, "parametric demand" is limited to the possibility of a 5% increase over the base case. Both 5% and 10% increases are considered for 1980, 1985, 1990 and 2000; 10% and 15% increases are examined for 2010; while 15% and 30% increases are included as possibilities for the year 2020.

The "parametric demand" cases simulate new uses for sulfur. However, they may also be considered as representing more expansive estimates of sulfur demand for existing uses. In either case, the possible differential would increase with time. Clearly, there is no chance of demand in 1975 being 30% higher than has been estimated, whereas such a possibility is conceivable for the year 2020. On the other hand, there is also a possibility that sulfur demand might develop more slowly than has been projected, in spite of the relatively low prices that are expected for many years. Under these circumstances, the viable outlet for abatement S in useful form would be reduced.

A.4.7 Foreign Supply Forecast

Projections of sulfur supplies from the "Free World ex U.S." are given in Table 43 on a geographical basis, and in Table 44 on a source basis. Some of the projections for Canada (in A.4.3.2 and A.4.4.2) are included in these summaries for the sake of completeness.

Mexican and Iraqi Frasch sulfur, which may well play important roles in deciding whether sulfur markets in the next few years are reasonably stable or chaotic, are expected to be of declining importance in later years.

Recovery of sulfur from sour natural gas is expected to peak about 1985. At the turn of the century, it is not expected to be a major factor in world supplies.

In 1970, recovery of sulfur from petroleum outside the U.S. approximated one million tons. The recovery level is projected to increase steadily until, by 1990, petroleum becomes the principal source of sulfur supply outside the U.S.

Recovery of S values from smelter gas and pyrite roasting is projected to increase slowly on balance, but with considerable differences in the pattern of supply from one geographic area to another.

"Other" sulfur supply refers to ammonium sulfate and many other sulfur-containing by-products that are produced on a relatively small scale. Overall, the level of such production is expected to increase slowly, mostly as a consequence of industrial development in the "developing countries": Latin America, Africa and Asia.

A.4.8 Foreign Supply/Demand Balances

Projections of demand/supply balances for the "Free World ex. U.S." are given in Table 45. These are net internal balances without taking trade with the U.S. and Communist countries into account. It will be seen that all of the "developing" areas, the Middle East/Far East (excluding Japan), Africa, and Latin America are projected to have growing net demands for sulfur. Much of the expanding demand will relate to P fertilizers while, on the supply side, proportionately less S will be recovered from fossil fuels (because of relatively lower energy demand). Derivation of the demand projections is discussed in Appendix 5.

Western Europe is projected to stay in a net demand position partly because of a healthy growth in industrial demand and partly because of access to North Sea and Netherlands gas and oil (which are of low S content). In the long run, W. Europe is expected to satisfy incremental industrial energy demand with nuclear power in order to decrease dependence on petroleum imports.

Japan has less access to natural gas than W. Europe, and imported LNG will be more expensive than Netherlands or North Sea gas. Although prospects for oil discoveries in Indonesia and the South China Sea appear good, the relationship of such oil to Japan will not be the same as that of North Sea oil to European countries. Furthermore, the industrializable land areas of Japan are small and will require a more rapid installation of pollution controls than in W. Europe. In consequence, Japan, which already has moved into sulfur surplus, is expected to stay in a surplus position. Japan may be expected to export sulfur to Pacific countries including Australia.

Although Canadian production of sulfur from sour gas is expected to peak soon after 1980, the country is expected to have a continuing surplus of production over domestic demand. In the later years of the forecast, smelters are projected to contribute much of the surplus. Recovery of elemental S from Canadian smelters is expected.

D/S balances for Communist countries are projected in Table 46, together with net exports from the Bloc. A surplus position is expected at least through 1990 because of growing exploitation of Polish deposits and also recovery of S from sour gas in the Orenburg area of the U.S.S.R. The surplus is expected to force a gradual curtailment of pyrite roasting. Longer range, and dependent upon the construction of a mammoth pipeline network, the U.S.S.R. will utilize sweet arctic gas. This is a principal reason for the projected reversal of the D/S balance between 1990 and 2000. At first, the net demand could be filled from S stockpiled over the next 20 years. Eventually, however, the net demand projected for 2010 and 2020 might be met by a re-expansion of pyrite roasting, by recovery of S from coal, and/or by switching P fertilizer manufacture to nitrophosphate processes. The net demand projected in Table 46 stems from using the same basis as that for the other countries. In practice, however, it seem more likely that the Bloc countries will withdraw from export markets before the turn of the century and will then fill their own demand from higher cost indigenous sources rather than becoming major importers of S from the U.S.

Table 47 draws on the previous projections in order to obtain the quantities of foreign supply and demand that are used in the computer calculations. These are the foreign components that affect the U.S. balance and prices. The computer model uses the following names:

Calgary = W. Canadian elemental S
Sudbury = E. Canadian sulfuric acid
Coatzacoalcos = Mexican Frasch S
Aruba = Caribbean recovered S

The bottom line of Table 45, after correction for imports from the Communist Bloc (bottom of Table 46), shows a net surplus until 1990 but a net deficit subsequently. The implication is that the U.S. can become a substantial net exporter again in these subsequent years. Availability of U.S. sulfur for export will depend to a considerable degree on the way in which recovery of abatement S evolves. For example, the existence of a national stockpile of S would make substantial exports more likely. In contrast, if effective technology for recovery in elemental form is not developed, export potential would be lower. In consequence, a resurgence of pyrite roasting and nitrophosphate processing would be expected in potential export markets. However, as long as exported S can be delivered at prices less than $35-40/LT in N. Europe, there is little likelihood of re-expansion of pyrite roasting in N. Europe.

It should also be pointed out that the projections beyond the year 2000 become increasingly sensitive to assumptions made about the extent to which nuclear power will replace fossil fuels both for electricity generation and for industrial process heat. If nuclear power develops very rapidly outside the U.S., the pinch in S supply would occur sooner than projected in Table 45. For the later years of the forecast, the size of the projected net demand is less important than the projection of the reversal of D/S balance around the year 1990. This is because the reversal implies steadily strengthening values for recovered S up to the cost of either the next supply source (e.g., pyrite) or alternative of meeting demand (e.g., nitrophosphates). Thus, the projected reversal implies that recovered S will move up to a delivered value of about $35/LT in the 1990's. Subtraction of the delivery cost, e.g., from an Illinois Waterway stockpile to Rotterdam, amounting to just over $10/LT on a constant dollar basis, suggests that the net-back to a well-located electric utility may be in the range of $20-25/LT (in the 1990's) versus about $12-13/LT for the same hypothetical transaction today.

APPENDIX 4

Table 1

U.S. (Frasch) Sulfur Domes

- Closed Domes

Company	Dome	Years of Operation	Approx. Output 10^6 LT
Union	Sulfur Mine, La.	1894 - 1924	9.4
	Big Creek	1925 - 1926	*
	Boling Dome	1928 - 1929	*
Baker Williams	Boling Dome	1935	*
Allied Chemical	Sulfur Mine, La.	1966 - 1970	*
Phelan Sulphur	Nash	1966 - 1970	0.2
Standard Sulphur	Damon	1953 - 1957	0.1
Mecom	Chacahoula	1967 - 1970	0.1
U.S. Sulphur	High Island	1960 - 1962	*
Duval (1)	Palangana	1928 - 1935	0.2
	Boling Dome	1935 - 1940	0.6
	Orchard Dome	1938 - 1970	5.4
	Ft. Stockton**	1968 - 1970	0.5
Jefferson Lake (2)	Lake Peigneur	1932 - 1936	0.4
	Clemens Dome	1937 - 1960	3.0
	Long Point	1946 - 1970	5.6
	Starks Dome	1951 - 1960	0.8
Hooker Chemical (2)	Bryan Mound	1967 - 1968	*
Freeport	Bryan Mound	1912 - 1935	5.0
	Hoskins Mound	1923 - 1955	10.9
	Bay St. Elaine	1952 - 1959	1.1
	Nash	1954 - 1956	0.2
	Chacahoula	1955 - 1962	1.2
	Caminada	1968 - 1970	0.3
Texas Gulf	Gulf	1919 - 1936	12.8
	Long Point	1930 - 1938	0.4

* less than 100,000 LT

APPENDIX 4

Table 2

U.S. (Frasch) Sulfur Domes

- Operating Domes

Company	Dome	Cumulative Production to 1966, 10^6 LT
Pan Am. Pet.	High Island	-
Sinclair	Ft. Stockton *	N.A.
Duval (1)	Culbertson County ϕ	-
Jefferson Lake (2)	Long Point	4.6
	Tilden	N.A.
	Lake Hermitage	N.A.
Freeport	Grand Ecaille	30.9
	Garden I. Bay	7.0
	Grand Isle	4.5
	Lake Pelto	2.5
Texas Gulf	Boling	61.1
	Spindletop	6.3
	Moss Bluff	5.1
	Fannett	1.8
	Bully Camp	-

* Modified - Frasch
(1) Pennzoil United
(2) Occidental Petroleum
ϕ Producible by Frasch technique, although not a salt dome.

Sources: "The Economics of the Sulphur Industry", Hazleton, RFF, 1970.

Annual Reports of Occidental Petroleum, Freeport and other Companies.

APPENDIX 4

Table 3

Frasch Sulfur Reserves

- Estimated Remaining Reserves

	Million Long Tons
Grand I, Grand Ecaille, Garden I. Bay, Lake Pelto	80
Boling, Spindletop, Bullycamp, Moss Bluff, Fannett	65
Culbertson County	57
Other U.S. Frasch and Mod-Frasch	8
	210
Mexican Domes	
Jaltipan, Nopalapa, Salinas, Texistipec	70
	280

- Hypothetical production of U.S. Frasch sulfur (in order to obtain a concept of time at which reserves may become depleted) - million LT.

Production To		Reserves Remaining
1975	33	177
1980	28	149
1985	24	125
1990	20	105
2000	40	65
2010	40	25

- Depleted by 2020.

- If production were to continue at an average rate of 6 million LT/yr, reserves would be depleted by the year 2005.
- Mexican reserves appear adequate to support production of approx. 1.7 million LT/yr for 40 years, i.e., until the year 2010. Additional discoveries are possible.

- Sources of Information

(1) SRI Chemical Economics Handbook

(2) "The Economics of the Sulphur Industry"

(3) U.S. Bureau of Mines

(4) "Sulphur" Magazine, Jan/Feb 1971 (For Culbertson Co. estimate)

APPENDIX 4

TABLE 4

REGIONAL DISTRIBUTION OF U.S. PETROLEUM REFINING CAPACITY

Region No.	Reference Point	State	No. of Refineries	Capacity MB/SD	% of 48 States	Hydrotreating		Akylation, MB/SD	
						MB/SD	%	H_2SO_4	HF
1	Boston	R.I.	1	7.5	0.1	--	--	--	--
2	Newark	N.Y.	2	87.4	0.7	40.1	0.9	--	2.8
		N.J.	6	519.8	4.1	188.2	4.3	19.2	2.3
		Pa.	12	649.1	5.2	297.4	6.9	29.4	--
			20	1256.3	10.0	525.7	12.1	48.6	5.1
3	Norfolk	Md.	2	18.4	0.1	--	--	--	--
		Del.	1	140.0	1.1	88.0	2.0	5.0	--
		W.Va.	2	8.4	0.1	4.0	0.1	--	--
		Va.	1	51.4	0.4	24.1	0.6	--	--
		Ga.	2	8.8	0.1	--	--	--	--
			8	227.0	1.8	116.1	2.7	5.0	--
4	Chicago	Mich.	7	156.8	1.2	54.3	1.3	6.7	1.2
		Ohio	8	532.0	4.2	171.3	3.9	18.0	15.1
		Ind.	9	598.3	4.8	180.9	4.2	29.7	3.1
		Ill.	10	846.1	6.7	334.6	7.7	49.3	21.1
		Wis.	2	39.0	0.3	9.2	0.2	--	1.2
			36	2172.2	17.2	750.3	17.3	103.7	41.7
5	Memphis	Ky.	3	150.4	1.2	39.0	0.9	--	--
		Tenn.	1	28.5	0.2	--	--	--	3.0
		Ala.	5	37.7	0.3	5.5	0.1	--	--
			9	216.6	1.7	44.5	1.0	--	3.0

Source: Oil and Gas Journal, 3/22/71

APPENDIX 4

TABLE 4 con't.

Region No.	Reference Point	State	No. of Refineries	Capacity MB/SD	% of 48 States	Hydrotreating		Alkylation, MB/SD	
						MB/SD	%	H_2SO_4	HF
6	Omaha	Minn.	3	151.5	1.2	66.9	1.5	7.0	2.5
		Mo.	1	83.0	0.7	20.0	0.5	4.5	--
		N.D.	2	55.0	0.4	9.0	.0.2	--	2.8
		Nebr.	1	5.0	negl.	--	--	--	--
		Kan.	11	378.0	3.0	84.1	1.9	--	36.1
			18	672.5	5.3	180.0	4.1	11.5	41.4
7	Seattle	Wash.	5	225.5	1.8	100.2	2.3	14.2	3.8
		Oreg.	1	11.0	0.1	--	--	--	--
8	Los Angeles	Cal.	34	1700.9	13.5	694.2	16.0	73.4	13.5
9	Tampa	Fla.	1	3.1	negl.	--	--	--	--
10	Tueson	Mont.	9	126.8	1.0	60.7	1.4	--	8.4
		Wyo.	9	138.9	1.1	65.0	1.5	3.0	1.3
		Col.	4	44.7	0.4	16.9	0.4	--	--
		N.M.	5	42.7	0.3	10.7	0.2	--	3.1
		Nev.	1	0.5	negl.	--	--	--	--
		Utah	5	117.7	0.9	14.0	0.3	4.0	6.9
			33	471.3	3.7	167.3	3.8	7.0	19.7
11	New Orleans	Ark.	6	93.5	0.7	26.0	0.6	4.0	2.5
		La.	17	1306.5	10.4	213.7	4.9	90.9	4.5
		Okal.	13	463.7	3.7	82.5	1.9	5.1	31.7
		Tex.	43	3469.8	27.5	1423.3	32.8	145.9	68.9
		Miss.	5	311.7	2.5	21.0	0.5	13.0	--
			84	5645.2	44.8	1766.5	40.7	258.9	107.6
	48 State Total		250	12609.1	100	4344.8	100	522.2	235.8

APPENDIX 4

TABLE 5

ELEMENTAL SULFUR RECOVERY FROM REFINERY GAS

Region No.	State	Location	Company	Capacity 1000 LT/yr.
2	N.Y.	Buffalo	Ashland	20
	N.J.	Elizabeth	Allied Chem.*	20
		Port Reading	Amerada - Hess	15
		Perth Amboy	Anlin*	18
		Eagle Point	Freeport*	15
		Paulsboro	Mobil	25
		Bayway	Humble	50
				143
	Pa.	Philadelphia	Arco	10
		Philadelphia	Gulf	16
		Marcus Hook	Sohio/B.P.	15 est.
		Marcus Hook	Sun	15
				56
			Region Subtotal 219	
3	Del	Delaware City	Getty	122
	Va.	Yorktown	Indiana	23
			Region Subtotal 145	
4	Mich.	Alma	Leonard Ref.	4
		Detroit	Marathon	40
		Trenton	Mobil	10
				54
	Ohio	Toledo	Sohio/B.P.	11
		Toledo	Sun	5
				16
	Ind.	E.Chicago	Arco	30 est.
		Whiting	Indiana	30
				60
	Ill.	Wood River	Anlin*	53
		Robinson	Marathon	55
		Lemont	Union	11
				79
			Region Subtotal 209	
5	Ky.	Catlettsburg	Ashland	N.A. (1)
			Region Subtotal N.A.	

TABLE 5 con't.

Region No.	State	Location	Company	Capacity 1000 LT/yr.
6	Minn.	St. Paul	Ashland	6
		Pine Bend	Koch Ind.	46
				52
	Mo.	Sugar Creek	Indiana	35
	Kan.	Coffeyville	Farmland Ind.	2
		Kansas City	Phillips	13
				15
			Region Subtotal 102	
8	Cal.	El Segundo	Allied Chem.*	45
		Wilmington	Arco	25
		Paramount	Conoco	38
		Santa Fe Springs	Gulf	11
		Torrance	Mobil	30
		Avon	Monsanto*	55
		Santa Fe Springs	Powerine	7
		Martinez	Shell	15
		Benicia	Humble	50
		Long Beach	Stauffer*	91
		Wilmington	Texaco	25
		Arroyo Grande	Union	19
		Rodeo	Union	19
		Wilmington	Union	40
		Wilmington	Union Pacific	10
				480
			Region Subtotal 480	
10	Mont.	Laurel	Farmers Union	5
		E. Billings	Montana Sulphur*	35
				40
	N.M.	Artesia	Phillips	4
	Col.	Denver	Conoco	N.A. (1)
	Wyo.	Sinclair	Arco	N.A. (1)
			Region Subtotal 44+	

TABLE 5 con't.

Region No.	State	Location	Company	Capacity 1000 LT/yr.
11	Miss.	Purvis	Gulf	11
	Ark.	El Dorado	Monsanto*	5
	La.	Lake Charles	Cities Service	16
		Norco	Shell	12
		Baton Rouge	Humble	5
		Baton Rouge	Stauffer	18
				51
	Tex.	Port Arthur	Arco	25
		Port Arthur	Gulf	52
		Beaumont	Olin	15
		Goldsmith	Phillips	30
		Sweeney	Phillips	10
		Houston	Shell	35
		Houston	Signal	15
		Port Arthur	SOhio/B.P.	20
		Baytown	Stauffer*	35
		Big Spring	Sulpetro	5
				242
			Regional Subtotal 309	

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* Chemical companies which recover sulfur from H_2S streams supplied by Petroleum Refineries

Sources: 1971 Directory of Chemical Producers, S.R.I.
(1) Freeport Minerals' Testimony to U.S. Tariff Commission

APPENDIX 4

TABLE 6

REGIONAL SUMMARY OF SULFUR RECOVERY FROM REFINERY GAS

Region No.	State	Capacity 1000 LT/yr.	Capacity %	% of Capacity Operated By Chemical Cos.
2	N.Y.	20	1.3	NIL
	N.J.	143	9.5	37
	Pa.	56	3.7	NIL
		219	14.5	24
3	Del.	122	8.1	NIL
	Va.	23	1.5	NIL
		145	9.6	NIL
4	Mich.	54	3.6	NIL
	Ohio	16	1.1	NIL
	Ind.	60	4.0	NIL
	Ill.	79	5.2	67
		209	13.9	25
5	Ky.	N.A.	N.A.	NIL
6	Minn.	52	3.5	88
	No.	35	2.3	NIL
	Kan.	15	1.0	NIL
		102	6.8	45
8	Cal.	480	31.8	40
10	Col.	N.A.	N.A.	NIL
	Wyo.	N.A.	N.A.	NIL
	Mont.	40	2.6	88
	N.M.	4	0.3	NIL
		44	2.9	80
11	Miss.	11	0.7	NIL
	Ark.	5	0.3	100
	La.	51	3.4	NIL
	Tex.	242	16.1	14
		309	20.5	13
TOTAL		1508+	100	28

APPENDIX 4

TABLE 7

PROJECTED GEOGRAPHICAL DISTRIBUTION OF RESIDENT POPULATION OF CONTINENTAL U.S.

(% Basis)

Region No.	Reference Point	1970	1975	1980	1985	1990	2000	2010	2020
1	Boston	5.87	5.86	5.85	5.79	5.73	5.55	5.34	5.14
2	Newark	18.38	18.00	17.61	17.23	16.85	16.13	15.46	14.84
3	Norfolk	11.81	11.83	11.85	11.80	11.75	11.64	11.52	11.44
4	Chicago	19.92	19.74	19.55	19.34	19.13	18.73	18.33	17.96
5	Memphis	5.23	5.08	4.93	4.83	4.72	4.56	6.46	4.39
6	Omaha	8.09	7.81	7.56	7.34	7.12	6.82	6.59	6.41
7	Seattle	2.72	2.78	2.85	2.91	3.00	3.16	3.36	3.52
8	Los Angeles	9.88	10.41	10.94	11.44	11.94	12.89	13.79	14.60
9	Tampa	3.36	3.66	3.95	4.23	4.50	4.98	5.43	5.83
10	Tucson	4.08	4.20	4.32	4.47	4.62	4.78	4.81	4.79
11	New Orleans	10.66	10.63	10.59	10.62	10.64	10.76	10.91	11.08
	Total	100	100	100	100	100	100	100	100
Millions Mid-year		202.1	214.0	226.2	239.0	252.4	278.7	304.7	329.7

APPENDIX 4

TABLE 8

PROJECTED DISTRIBUTION OF U.S. PETROLEUM REFINING CAPACITY

(% Basis)

Region No.	Reference Point	1970	1975	1980	1985	1990	2000	2010	2020
1	Boston	0.1	0.1	0.4	0.5	0.7	1.0	1.3	1.6
2	Newark	10.0	9.8	9.5	9.3	9.0	8.5	8.1	7.7
3	Norfolk	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7
4	Chicago	17.2	16.8	16.5	16.2	16.0	15.6	15.1	14.7
5	Memphis	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4
6	Omaha	5.3	5.2	5.0	4.9	4.7	4.4	4.2	4.0
7	Seattle	1.9	2.0	2.0	2.1	2.1	2.2	2.2	2.3
8	Los Angeles	13.5	14.2	14.6	15.2	15.7	16.8	17.9	18.9
9	Tampa	negl.	negl.	0.4	0.8	1.2	1.9	2.6	3.3
10	Tucson	3.7	3.7	3.8	3.8	3.9	4.0	4.0	4.1
11	New Orleans	44.8	44.7	44.4	43.8	43.5	42.4	41.5	40.3

APPENDIX 4

TABLE 9

PROJECTIONS OF SULFUR IN U.S. PETROLEUM SUPPLY

(Millon LT of S Equivalent)

Sulfur In	1970	1975	1980	1985	1990	2000	2010	2020
Total Petroelum Supply	4.6	5.6	6.2	7.1	8.4	11.9	16.6	22.3
Refinery Runs	3.3	4.3	5.1	6.1	7.4	10.9	15.6	21.1
Domestic Products	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Imported Products	1.3	1.3	1.1	1.0	1.0	1.0	1.0	1.2
Total Products	2.8	2.8	2.6	2.5	2.5	2.5	2.5	2.7
Recovered Elemt.	0.9	2.0	2.9	3.9	5.2	8.7	13.4	18.9
Recovered Acid	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Recovered Total	1.1	2.2	3.1	4.1	5.4	8.9	13.6	19.1
Refinery Emissions	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Refinery Emissions %	21	14	10	8	7	5	3	2

APPENDIX 4

TABLE 10

REGIONALIZED PROJECTIONS OF ELEMENTAL SULFUR RECOVERED FROM U.S. PETROLEUM REFINERIES (MILLION LT)

Region No.	Reference Point	1970	1975	1980	1985	1990	2000	2010	2020
1	Boston	--	--	--	0.1	0.1	0.1	0.2	0.3
2	Newark	0.13	0.2	0.2	0.3	0.4	0.7	1.1	1.6
3	Norfolk	0.09	0.1	0.1	0.1	0.1	0.1	0.2	0.4
4	Chicago	0.12	0.3	0.4	0.6	0.8	1.3	2.0	3.0
5	Memphis	0.01	0.1	0.1	0.1	0.1	0.1	0.2	0.3
6	Omaha	0.06	0.1	0.1	0.2	0.2	0.4	0.6	0.8
7	Seattle	--	--	0.1	0.1	0.1	0.2	0.3	0.4
8	Los Angeles	0.28	0.4	0.6	0.8	1.0	1.7	2.6	3.6
9	Tampa	--	--	0.1	0.1	0.2	0.3	0.4	0.6
10	Tucson	0.03	0.1	0.1	0.2	0.2	0.4	0.6	0.8
11	New Orleans	0.18	0.7	1.1	1.3	2.0	3.4	5.2	7.0
Total		0.90	2.0	2.9	3.9	5.2	8.7	13.4	18.8

- Recovery as Acid

2	Newark	0.04
7	Seattle	0.01
8	Los Angeles	0.03
10	Tucson	0.01
11	New Orleans	0.11
		0.20

APPENDIX 11

TABLE 11

SULFURIC ACID PLANTS THAT USE H_2S AND SPENT ACID (ACID SLUDGE) AS FEEDSTOCK

Region No.	State	Location	Company	Capacity 1000 ST/YR	Feed** S.A.	Feed** H_2S
2	N.Y.	Buffalo	Allied Chem.	195	x	x
	N.J.	Elizabeth	Allied Chem.	200	x	
		Linden	Du Pont	325	x	
		Newark	Essex Chem.	180		x
		Paulsboro	Olin	300	x	
	Pa.	Newell	Allied Chem.	250	x	
		Philadelphia	Arco*	140	x	x
		Pittsburgh	U.S.S. Agrichem.	50		x
		Petrolia	Witco	45	x	
3	Del.	N. Claymont	Allied Chem.	350	x	
4	Mich.	Detroit	Allied Chem.	200	x	
	Ind.	E. Chicago	Du Pont	375	x	
		Hammond	Stauffer	275	x	
	Ill.	Chicago	Allied Chem.	160	x	
		Elwood	Am. Can	325	x	
5	Ky.	Wurtland	Du Pont	200	x	
7	Wash.	Anacortes	Allied Chem.	80	x	x
8	Cal.	Bay Point	Allied Chem.	140	x	
		El Segundo	Allied Chem.	180	x	x
		Richmond	Allied Chem.	220	x	x
		Avon	Monsanto	135	x	x
		Los Angeles	Stauffer	325	x	
		Martinez	Stauffer	350	x	
		Wilmington	Union*	140	x	x
10	N.M.	Monument	Climax Chem.	75		x

APPENDIX 4

TABLE 11 cont'd

Region No.	Stat	Location	Company	Capacity 1000 ST/YR	Feed** S.A.	Feed** H_2S
11	La.	Baton Rouge	Allied Chem.	100	x	
		Lake Charles	Cities Service*	150	x	x
		Burnside	Du Pont	510	x	
		Baton Rouge	Stauffer	450	x	
	Tex.	Dumas	Diamond Shamrock*	35	x	x
		La Porte	Du Pont	350	x	
		Port Arthur	Gulf*	140	x	x
		Texas City	Indiana*	175	x	x
		Baytown	Stauffer	275	x	x
		Houston	Stauffer	1400	x	x
		Port Arthur	Texaco*	95	x	x
		Beaumont	Olin	190	x	x

* Direct part of petroleum refining operations

** Most of the above plants also use elemental S as feed.

Source: 1971 Directory of Chemical Producers, Stanford Research Institute.

APPENDIX 4

TABLE 12

SUMMARY OF U.S. SOUR NATURAL GAS SULFUR RECOVERY CAPACITY

Region No.	State	Recovery Capacity 1000 LT/YR of S
6	N.D.	52
10	N.M.	49
	Wyo.	84
	Utah	5
		138
11	Miss.*	5
	Ark.	30
	Okla.	8
	Tex.	892
		935
Total		1125

* Excluding 400,000 LT/YR of new capacity to be brought on stream at Jackson, Miss.

Note: A relatively small amount of S will also be recovered from the Jay-Little Field in the Florida Panhandle

Sources: Oil and Gas Journal, 7/21/71
1971 Directory of Chemical Producers, S.R.I.

APPENDIX 4

TABLE 13

REGIONALIZED PROJECTIONS OF ELEMENTAL SULFUR RECOVERY FROM U.S. NATURAL AND SYNTHETIC GAS (MILLION LT)

- Natural Gas

Region No.	Reference Point	1970	1975	1980	1985	1990	2000	2010	2020
6	Omaha	0.046	0.06	0.06	0.07	0.07	0.07	0.07	0.07
10	Tucson	0.073	0.09	0.09	0.10	0.10	0.10	0.10	0.10
11	New Orleans	0.541	1.04	1.50	1.57	1.37	0.82	0.77	0.77
	Subtotal	0.660	1.19	1.65	1.74	1.54	0.99	0.94	0.94

- Synthetic Gas (from coal)

Region No.	Reference Point	1970	1975	1980	1985	1990	2000	2010	2020
4	Chicago	--	--	--	negl.	0.33	1.29	2.51	3.77
10	Tucson	--	--	--	negl.	0.14	0.55	1.07	1.62
	Subtotal	--	--	--	negl.	0.47	1.83	3.58	5.39

- Combined Totals

Region No.	Reference Point	1970	1975	1980	1985	1990	2000	2010	2020
4	Chicago	--	--	--	--	0.33	1.29	2.51	3.77
6	Omaha	0.046	0.06	0.06	0.07	0.07	0.07	0.07	0.07
10	Tucson	0.073	0.09	0.09	0.10	0.24	0.65	1.17	1.72
11	New Orleans	0.541	1.04	1.50	1.57	1.37	0.82	0.77	0.77
	Total	0.660	1.19	1.65	1.74	2.01	2.83	4.52	6.33

APPENDIX 4

TABLE 14

REGIONALIZED PROJECTIONS OF ELEMENTAL SURFUR RECOVERY FROM PETROLEUM*, NATURAL GAS AND SYNTHETIC GAS (MILLION LT)

Region No.	Reference Point	1975	1980	1985	1990	2000	2010	2020
1	Boston	--	--	0.10	0.10	0.10	0.20	0.30
2	Newark	0.24	0.24	0.34	0.44	0.74	1.14	1.54
3	Norfolk	0.10	0.10	0.10	0.10	0.10	0.20	0.30
4	Chicago	0.30	0.40	0.60	1.13	2.59	4.51	6.57
5	Memphis	0.10	0.10	0.10	0.10	0.10	0.20	0.30
6	Omaha	0.16	0.16	0.27	0.27	0.47	0.67	0.87
7	Seattle	0.01	0.11	0.11	0.11	0.21	0.31	0.41
8	Los Angeles	0.43	0.63	0.83	1.03	1.73	2.63	3.63
9	Tampa	--	0.10	0.10	0.20	0.30	0.40	0.60
10	Tucson	0.20	0.20	0.31	0.46	1.07	1.79	2.53
11	New Orleans	1.85	2.71	2.98	3.48	4.33	6.08	8.38
Total		3.39	4.75	5.84	7.42	11.74	18.13	25.43
% of Total From								
Petroleum		65	65	70	73	76	75	75
Natural Gas		35	35	30	21	8	5	4
Synthetic Gas (Coal)		--	--	--	6	16	20	21

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* Making the simplifying assumptions (1) that future recovery from petroleum refineries will be as elemental S rather than acid, and (2) combining the current level of 0.2 million LT/YR of S equivalent in acid form into the above projections.

APPENDIX 4

TABLE 15

Capacities of Plants Processing Sour Natural Gas in Western Canada

Company	Location	1st Yr. on Stream	Cost SMM	Gas, MMCFD		R/P %	1970 Raw MMCFD	% of Capacity	S Capac. LT/D	S 1970 MLT
				Raw	Product					
Amerada	Olds	1964	5.0	100	72	72	39	39	600	85.4
Amoco(1)	Bigstone	1968	2.0	56	43	77	49	88	376	120.8
Amoco(1)	Crossfield	1965	12.5	193	114	59	157	81	1610	476.0
Amoco/TGS	Windfall	1961	22.0	371	136	37	296	80	1875	547.5
Arco	Gold Creek	1970	7.0	52	40	77	20	38	105	14.7
Aquitaine	Rainbow	1968	15.0	75	30	40	40	53	70	13.6
Aquitaine	Ram River	1971	25.0	220	150	68	--	--	2032	--
Can. Delhi	Buck Lake	1961	4.0	108	100	93	56	52	32	6.1
Can. Fina	Wildcat Hills	1961	5.2	125	115	92	93	74	135	36.7
Can. Superior	Harmattan	1966	0.5	42	16	38	33	79	805	232.1
Can. Superior	Lone Pine Cr.	1971	4.0	30	22	73	--	--	130	--
Chevron(2)	Kaybcb S	1971	80.0	445	284	64	--	--	2850	--
Chevron(2)	Nevis	1959	7.6	79	70	89	61	77	200	56.2
Gulf Oil	Nevis	1956	8.6	116	70	60	73	63	198	45.5
Gulf Oil	Pincher Creek	1957	30.3	148	114	77	105	71	326	84.5
Gulf Oil	Rimbey	1961	20.0	422	357	85	397	94	326	111.9
Gulf Oil	Strachan	1971	25.0	250	201	80	--	--	840	--
Gulf Oil	Turner Valley	1933	7.9	88	85	97	38	43	30	4.7
Home Oil	Carstairs	1960	15.0	350	280	80	258	74	46	12.4
H.B.O.G.(3)	Brazeau R.	1969	8.5	102	90	88	67	66	32	7.7
H.B.O.G.(3)	Caroline	1968	6.5	55	27	67	35	64	18	4.2
H.B.O.G.(3)	Edson	1965	11.0	371	337	91	282	76	285	79.1
H.B.O.G.(3)	Kaybob S.	1968	25.0	212	154	73	127	60	1044	228.6
H.B.O.G.(3)	Kaybob S.	1970	20.0	170	113	66	117	69	1030	259.4
H.B.O.G.(3)	Lone Pine Cr.	1967	5.5	50	40	80	39	78	175	49.8
H.B.O.G.(3)	Sturgeon L.	1969	12.0	28	12	43	9	32	62	7.2
H.B.O.G.(3)	Sylvan L.	1965	2.0	59	54	92	48	81	13	3.9
Imperial(4)	Quirk Cr.	1971	8.0	90	68	76	--	--	240	--
Imperial(4)	Redwater	1956	2.2	10	6	60	9	90	9	3.0
Imperial(4)	Redwater	1971	1.0	7	5	71	--	--	7	--

TABLE 15 (Cont'd)

Company	Location	1st Yr. on Stream	Cost $MM	Gas, MMCFD Raw	Gas, MMCFD Product	R/P %	1970 Raw MMCFD	% of Capacity	S Capac. LT/D	S 1970 MLT
Occidental	Crossfield	1961	30.0	312	216	69	263	84	1970	606.2
Occidental	Peale R.	1957	22.0	435	400	92	385	89	300	96.9
Occidental	Coleman	1961	6.1	75	59	79	13	17	795	50.2
Mobil	Wimbourne	1965	5.0	70	53	76	44	63	395	90.8
Shell	Burnt Timber	1970	4.0	57	47	82	16	28	187	19.2
Shell	Innisfail	1960	2.6	15	10	67	8	53	115	22.4
Shell	Jumping Pound	1951	4.0	248	200	81	146	59	430	92.6
Shell	Simonette	1969	2.0	15	11	73	11	73	90	24.0
Shell	Waterton	1961	46.0	473	315	67	260	55	2970	596.2
Steelman	Steelman	1958	6.0	38	30	79	28	74	8	2.2
Tenneco	Brazeau R.	1970	4.0	67	60	90	--	--	41	--
Tenneco	Nordegg	1970	3.0	67	59	88	42	63	40	9.2
TGS	Okotoks	1959	62	37	17	46	25	68	430	106.7
Westcoast T.	Fort Nelson	1965	33.6	820	760	93	475	60	100	21.9
Total (A)	--	--	572.8	7153	5452	76	4164	68*	23372	4229.5
Total Additions Projected for 1971			143.0	1042	730	70	--	--	6099	--
1971 Additions as % of Total			25.0	14.6	13.4	--	--	--	26.1	--
Total Gas Plant Capacity**		--	834.2	15210	13145	86	8580	70*	23488	--
(A) as % of Total		--	69	47	41	--	49	--	99.5	--

(1) Affiliate of Standard Oil of Indiana
(2) Affiliate of Standard Oil of California
(3) Affiliate of Continental Oil
(4) Affiliate of Standard Oil of New Jersey
* Of 1970 capacity
** Including plants processing sweet gas and plants in Eastern Canada

Source: Canadian Petroleum, June 1971.

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TABLE 16

Processing Costs for Canadian Sour Gas

	(A)	(B)	(C)	(D)
Sour Gas (Raw Gas)				
- Flow, MMCFD	50	50	50	50
- H_2S, Mol.%	0.5	10	20	35
- CO_2, Mol.%	3.0	5	5	10
- Hydrocarbons, Mol.%	96.5	85	75	55
Residue Gas (Product Gas)				
- Gross, MMCFD	48.25	42.50	37.50	27.50
- Plant fuel, MMCFD	0.60	1.55	2.11	3.53
- Sales, MMCFD	47.65	40.95	35.39	23.97
Investment, $MM				
- Field and gathering	1.71	2.74	2.74	2.85
- Processing(1)	1.17	4.17	6.92	9.55
- Total	2.88	6.91	9.66	12.40
Operating Cost ($/Day)				
- Field and gathering	330	475	535	585
- Processing	790	1360	1985	3030
- Total	1120	1835	2520	3615
Depreciation ($/Day)(2)				
- Field and gathering	467	749	751	781
- Processing	322	1144	1895	2617
- Total	789	1893	2646	3398
Op. Cost Plus Depreciation ($/Day)				
- Field and gathering	797	1224	1286	1366
- Processing	1122	2504	3880	6428
- Total	1909	3728	5166	7794
Cost of Product Gas				
- Field and gathering, ¢/MCF	1.7	3.0	3.6	5.7
- Processing, ¢/MCF	2.4	6.1	11.0	26.8
- Total, ¢/MCF	4.1	9.1	14.6	32.5
Sulfur Production, LT/D	--	190	380	665

(1) H_2S separation and conversion to elemental S
(2) 10% per year, straight line

Note: Return on investment is not included in above estimates.

Source: "Economics of the Sour Gas Industry," J. W. Estep and E. W. Plum, Texas Gulf Sulphur, "Sulphur" Jan./Feb. 1968.

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TABLE 17

Cost of Recovering Sulfur from Alberta Sour Gas

- Claus - type process for conversion of H_2S to elemental S.

Plant Capacity LT/D of S	100	300	1000
Actual Cost, \$/LT	5.80	3.96	2.64
Steam Credit, \$/LT	1.62	1.62	1.62
Net Cost, \$/LT	4.18	2.34	1.02

- Cost of H_2S separation, based on 300 LT/D of S production.

Mol.% H_2S in Raw Sour Gas	2	5	10	20
Separation Cost, \$/LT of S	19.4	11.5	8.9	7.7

- Typical cost for H_2S separation and conversion to elemental S, assigning total cost of operation to sulfur recovery (i.e. no charge against gas)*.

- \$9/LT

---

* Not unreasonable in 1968 when elemental sulfur prices were very high.

Note: OGJ of 9/2/68 is cited by author.

Source: "Alberta Sulphur 1968, the Promise and the Problems of the Industry in Alberta," J. B. Hyne.

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TABLE 18

Build up of Western Canadian Sour Gas Sulfur Recovery Capacity

Year	(1) LT/D	Cumulative LT/D	Cumulative 10^6 LT/Yr.	S Recovered 10^6 LT	S Recovered in Year As % of B.Y.* Capacity
1951	430	460	0.17	--	--
1956	207	667	0.24	0.03	18
1957	626	1293	0.47	0.09	38
1958	8	1301	0.47	0.16	35
1959	630	1931	0.70	0.26	56
1960	161	2092	0.76	0.37	53
1961	8103	10195	3.72	0.48	63
1962	--	10195	3.72	1.02	27
1963	--	10195	3.72	1.28	34
1964	600	10795	3.94	1.46	39
1965	3208	14003	5.11	1.58	40
1966	--	14003	5.11	1.72	34
1967	175	14178	5.17	2.12	41
1968	1508	15686	5.73	3.05	59
1969	184	15870	5.79	3.54	62
1970	1403	17273	6.30	4.13	71
1971 E	6099	23372	8.53	--	--

---

(1) Listed by the year in which the plants first went on stream.

* Beginning of year.

Source: Canadian Petroleum, April, May, June 1971 and June 1969.

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TABLE 19

Estimates of Quantities of Sulfur Associated With U.S. Smelting Operations

All Copper, Lead & Zinc Smelters	Millions of Long T of S Equivalent, or %							
	1970	1975	1980	1985	1990	2000	2010	2020
Generated	3.2	3.7	4.2	4.9	5.7	7.7	9.8	12.1
% Recovery	37	85	90	90	90	90	90	90
Recovered	1.2	3.1	3.8	4.4	5.1	6.9	8.8	10.8
Increment Over 1970	-	1.9	2.6	3.2	4.0	5.7	7.6	9.7
% of Inc. in Useful Form	-	40	40	40	40	40	40	40
Useful Increment	-	0.8	1.0	1.3	1.6	2.3	3.0	3.9
Total in Useful Form	1.2	2.0	2.2	2.5	2.8	3.5	4.2	5.0

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TABLE 20

Growth Rate Projections For U.S. Primary Production of Copper, Lead, and Zinc

Period	Compound Annual % Growth		
	Copper	Lead	Zinc
1970 - 1975	4.0	1.0	1.0
1975 - 1980	3.8	1.0	1.0
1980 - 1985	3.6	1.0	1.0
1985 - 1990	3.4	0.9	1.0
1990 - 2000	3.0	0.8	0.9
2000 - 2010	2.5	0.7	0.9
2010 - 2020	2.0	0.6	0.8

APPENDIX 4

TABLE 21

Separate Estimates of Quantities of Sulfur Associated With Primary Smelting of Copper Lead and Zinc in the U.S.

(Million LT of S Equivalent)

	1970	1975	1980	1985	1990	2000	2010	2020
• **Copper**								
Generated	1.9	2.3	2.7	3.2	3.8	5.2	6.6	8.0
% Recovery	21	70	90	90	90	90	90	90
Recovered	0.4	1.6	2.5	2.9	3.5	4.6	5.9	7.2
Inc. Over 1970	-	1.2	2.1	2.5	3.1	4.2	5.5	6.8
% In Useful Form	-	35	35	35	35	35	35	35
Useful Increment	-	0.4	0.7	0.9	1.1	1.5	1.9	2.4
Total in Useful Form	0.4	0.8	1.1	1.3	1.5	1.9	2.3	2.8
• **Lead**								
Generated	0.19	0.20	0.21	0.22	0.23	0.25	0.27	0.29
% Recovery	26	85	90	90	90	90	90	90
Recovered	0.05	0.17	0.19	0.20	0.21	0.23	0.24	0.26
Inc. Over 1970	-	0.12	0.14	0.15	0.16	0.18	0.19	0.21
% In Useful Form	-	90	90	90	90	90	90	90
Useful Increment	-	0.11	0.12	0.13	0.14	0.16	0.17	0.19
Total In Useful Form	0.05	0.16	0.17	0.18	0.19	0.21	0.22	0.24
• **Zinc**								
Generated	1.1	1.1	1.2	1.3	1.3	1.5	1.6	1.7
% Recovery	69	90	90	90	90	90	90	90
Recovered	0.75	1.0	1.1	1.1	1.2	1.3	1.4	1.6
Inc. Over 1970	-	0.3	0.3	0.4	0.4	0.6	0.7	0.8
% In Useful Form	-	95	95	95	95	95	95	95
Useful Increment	-	0.3	0.3	0.4	0.4	0.5	0.7	0.8
Total In Useful Form	0.75	1.0	1.1	1.1	1.2	1.3	1.4	1.5
• **Total**								
Generated	3.2	3.6	4.1	4.7	5.4	6.9	8.5	10.1
Recovered	1.2	2.8	3.7	4.3	4.9	6.2	7.6	9.1
Useful Form	1.2	2.0	2.3	2.6	2.8	3.4	4.0	4.5

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TABLE 22

SULFURIC ACID PLANTS UTILIZING SMELTER GASES

Region No.	State	Location	Company	Capacity 1000 ST/YR*
2	Pa.	Palmerton	N.J. Zinc (G + W Ind.)	384
		Josephtown	St. Joseph Minerals	265
		Newell	Allied Chem.	250 p
		Easton	C.K. Williams (Pfizer)	6 (1)
				905
3	Md.	Sparrows Pt.	Bethlehem Steel	90 p
	Del.	N. Claymont	Allied Chem.	350 p
				440
4	Ohio	Columbus	Am. Zinc	65
	Ill.	Fairmount City	Am. Zinc	145
		La Salle	Matthiesen & Hegler	55
		Depue	N.J. Zinc (G + W Ind.)	420
		E. St. Louis	C.K. Williams (Pfizer)	5 (1)
				690
5	Tenn.	Copper Hill	Tennessee Corp. (Citgo)	1260 (p)
6	Kan.	Galena	Eagle - Pitcher	150
	Mo.	Herculaneum	St Joseph Minerals	120
		Salem	Missouri Lead (2)	6
		Bixby	Amax	55
				331
7	Wash.	Tacoma	Asarco	55
8	Cal.	Selby	Asarco	14 (3)
10	Mont.	Anaconda	Anaconda	145
	Ida.	Kellogg	Bunker Hill (Gulf Resources)	230
	Col.	Denver	Allied Chem.	50 p (3)
	Utah	Garfield	Kennecott	575

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TABLE 22 Con't

Region No.	State	Location	Company	Capacity 1000 ST/YR*
	Ariz.	Bagdad	Bagdad Copper	64
		Hayden	Asarco	270
		Hayden	Kennecott	275
		San Manuel	Magma Copper	N.A.
		Morenci	Phelps Dodge	270
		Tucson	Newmont Mining	650 (4)
				2479
11	Okla.	Bartlesville	Nat. Zinc	100
	Tex.	Corpus Christi	Asarco	70
				170
			Total	6330

* Capacity estimates by different sources may vary because of different conversions of daily to annual basis, e.g., operating day assumptions ranging from 320-365.

p Source is pyrite

(p) Source is pyrite and NFM Smelter Gases

(1) Source is Ferrous Sulfate

(2) 50% owned by Amax

(3) To be shut down; capacity excluded from totals

(4) Proposed

Sources: Battelle Memorial Institute
Search
OPD Reporter
1971 Directory of Chemical Producers, S.R.I.
Freeport Minerals

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TABLE 23

REGIONALIZED PROJECTIONS OF GENERATION OF SULFUR VALUES BY U.S. SMELTERS

Region No.	Reference Point	1970	1975	1980	1985	1990	2000	2010	2020
1	Boston	--	--	--	--	--	--	--	--
2	Newark	0.286	0.318	0.337	0.368	0.380	0.426	0.473	0.521
3	Norfolk	0.044	0.046	0.048	0.050	0.053	0.58	0.063	0.068
4	Chicago	0.162	0.188	0.217	0.250	0.286	0.367	0.455	0.544
5	Memphis	0.308	0.327	0.347	0.368	0.391	0.437	0.486	0.535
6	Omaha	0.160	0.173	0.185	0.198	0.211	0.238	0.266	0.292
7	Seattle	0.057	0.063	0.070	0.079	0.087	0.106	0.126	0.146
8	Los Angeles	0.013	--	--	--	--	--	--	--
9	Tampa	--	--	--	--	--	--	--	--
10	Tucson	1.988	2.348	2.761	3.228	3.751	4.911	6.179	7.446
11	New Orleans	0.024	0.025	0.026	0.027	0.028	0.031	0.034	0.038
Continental U.S.		3.042	3.488	3.991	4.558	5.187	5.574	8.082	9.590
Rounded Total		3.1	3.5	4.0	4.6	5.2	6.6	8.1	9.6
● Percentage Basis									
Region No.									
2		9	9	8	8	7	6	6	5
3		1	1	1	1	1	1	1	1
4		5	5	5	5	6	6	6	6
5		10	10	9	8	8	7	6	6
6		5	5	5	4	4	4	3	3
7		2	2	2	2	2	2	2	2
8		1	-	-	-	-	-	-	-
10		66	67	69	71	72	74	76	77
11		1	1	1	1	1	-	-	-

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TABLE 24

MAXIMUM PERCENTAGES OF REGIONAL SULFUR DEMAND ESTIMATED TO BE POTENTIALLY AVAILABLE TO ABATEMENT ACID*

Region No.	Reference Point	1975	1980	1985	1990	2000	2010	2020
1	Boston	25	30	40	50	65	75	75
2	Newark	35	40	45	60	70	75	75
3	Norfolk	5	10	25	35	50	60	70
4	Chicago	15	20	35	50	60	75	75
5	Memphis	70	75	75	75	75	75	75
6	Omaha	33	35	38	40	45	50	60
7	Seattle	15	18	20	25	30	40	50
8	Los Angeles	5	5	10	15	20	30	40
9	Tampa	5	5	10	12	15	20	30
10	Tucson	90	90	90	90	90	90	90
11	New Orleans	5	5	10	10	15	20	20

* From Electric Utility stack gases and/or smelters

Note: In effect, what is being projected is the minimum percentage of total sulfur demand that will be supplied in elemental form. Reasons for such minima include:

- Demand for elemental S, e.g., in Pacific N.W. (Region No.7)
- Customer for S is also captive producer of elemental S
- Logistics, i.e., limitations on economic transportation of acid within region
- Need for evolution of market structure for abatement acid
- Need to keep some elemental S in the acid manufacuring picture in order to balance supply with demand, make oleum etc.

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TABLE 25

Projection of Sulfur Recovery From Canadian Smelting Operations (Millions of Long Tons of Sulfur Equivalent)

	1969	1970	1975	1980	1985	1990	2000	2010	2020
Total Generated	2.75	2.8	3.4	4.1	4.8	5.6	7.4	9.5	11.8
Total Recovered	0.55	0.6	1.5	3.6	4.3	5.0	6.7	8.5	10.6
Recovery									
- As Acid	0.55	0.6	1.1	1.5	1.9	2.3	3.1	4.0	5.2
- As El. S	**	**	0.2	0.3	0.5	0.9	1.9	2.9	3.9
- Other Forms*	**	**	0.2	1.8	1.9	1.8	1.7	1.6	.5

*Ammonium Sulfate, Waste Gypsum Etc.
**Very Small, Included With Acid.

- Growth Assumptions For Smelting:
  1970 - 80 3.8%/Yr.
  1980 - 85 3.5%/Yr.
  1985 - 90 3.2%/Yr.
  1990 - 00 2.8%/Yr.
  2000 - 10 2.5%/Yr.
  2010 - 20 2.2%/Yr.

- References:
  - "Enviromental Control in the Mining and Metallurgical Industries In Canada", National Advisory Committee on Mining and Metallurgical Research, Jan. 1971.
  - Wall St. Journal, 5/25/71.
  - International Nickel, 1970 Annual Report.
  - Allied Chemical, 1970 Annual Report.

APPENDIX 4

TABLE 26

REGIONALIZED PROJECTIONS OF U.S. SULFUR SUPPLY*

- 1975

Region	Million LT of S Equiv.			
No.	Gas	Pet.	Other	Total
1	--	--	--	--
2	--	0.20	0.27	0.47
3	--	0.10	0.04	0.14
4	--	0.30	0.16	0.46
5	--	0.10	0.28	0.38
6	0.06	0.10	0.15	0.31
7	--	--	0.05	0.05
8	--	0.40	--	0.40
9	--	--	--	--
10	0.09	0.10	0.65	0.84
11	1.04	0.70	0.01	1.75
	1.19	2.00	1.61	4.80

- 1980

Region	Million LT of S Equiv.			
No.	Gas	Pet.	Other	Total
1	--	--	--	--
2	--	0.20	0.30	0.50
3	--	0.10	0.04	0.14
4	--	0.40	0.19	0.59
5	--	0.10	0.31	0.41
6	0.06	0.10	0.17	0.33
7	--	0.10	0.06	0.16
8	--	0.60	--	0.60
9	--	0.10	--	0.10
10	0.09	0.10	0.80	0.99
11	1.50	1.10	0.01	2.61
	1.65	2.90	1.88	6.43

- 1985

Region	Million LT of S Equiv.			
No.	Gas	Pet.	Other	Total
1	--	0.10	--	0.10
2	--	0.30	0.33	0.63
3	--	0.10	0.04	0.14
4	--	0.60	0.22	0.82
5	--	0.10	0.33	0.43
6	0.07	0.20	0.18	0.45
7	--	0.10	0.07	0.17
8	--	0.80	--	0.80
9	--	0.10	--	0.10
10	0.10	0.20	0.97	1.27
11	1.57	1.30	0.01	2.88
	1.74	3.90	2.15	7.79

- 1990

Region	Million LT of S Equiv.			
No.	Gas	Pet.	Other	Total
1	--	0.10	--	0.10
2	--	0.40	0.34	0.74
3	--	0.10	0.05	0.15
4	0.33	0.80	0.26	1.39
5	--	0.10	0.35	0.45
6	0.07	0.20	0.19	0.46
7	--	0.10	0.08	0.18
8	--	1.00	--	1.00
9	--	0.20	--	0.20
10	0.24	0.20	1.20	1.64
11	1.37	2.00	0.02	3.39
	2.01	5.20	2.45	9.70

---

* U.S. Frasch supply and U.S. abatement potential are each dealt with separately elsewhere.

TABLE 26

(Cont'd)

- 2000

Region No.	Million LT of S Equiv. Gas	Pet.	Other	Total
1	--	0.10	--	0.10
2	--	0.70	0.38	1.08
3	--	0.10	0.05	0.15
4	1.29	1.30	0.33	2.92
5	--	0.10	0.37	0.49
6	0.07	0.40	0.21	0.68
7	--	0.20	0.09	0.29
8	--	1.70	--	1.70
9	--	0.30	--	0.30
10	0.65	0.40	1.72	2.77
11	0.82	3.40	0.03	4.25
	2.83	8.70	3.20	14.73

- 2010

Million LT of S Equiv. Gas	Pet.	Other	Total
--	0.20	--	0.20
--	1.10	0.43	1.53
--	0.20	0.06	0.26
2.51	2.00	0.41	4.92
--	0.20	0.44	0.64
0.07	0.60	0.24	0.91
--	0.30	0.11	0.41
--	2.60	--	2.60
--	0.40	--	0.40
1.17	0.60	2.35	4.12
0.77	5.20	0.03	6.00
4.52	13.40	4.07	21.99

- 2020

Region No.	Million LT of S Equiv. Gas	Pet.	Other	Total
1	--	0.30	--	0.30
2	--	1.60	0.47	2.07
3	--	0.40	0.06	0.46
4	3.77	3.00	0.497	7.26
5	--	0.30	0.48	0.78
6	0.07	0.80	0.26	1.13
7	--	0.40	0.13	0.53
8	--	3.60	--	3.60
9	--	0.60	--	0.60
10	1.72	0.80	3.05	3.57
11	0.77	7.00	0.03	7.80
	6.33	18.80	4.97	30.10

APPENDIX 4

TABLE 27

PARAMETRIC CASES OF U.S. REGIONALIZED SUPPLY

- 1975

Region No.	Regional Supply Ø	Regional Abatement Supply				
		(1)	(2)	(3)	(4)	(5)
1	--	0.01	0.01	0.02	0.02	0.03
2	0.47	0.05	0.08	0.11	0.15	0.23
3	0.14	0.03	0.06	0.09	0.12	0.17
4	0.46	0.16	0.27	0.41	0.55	0.82
5	0.38	0.04	0.07	0.10	0.13	0.20
6	0.31	0.03	0.04	0.07	0.09	0.13
7	0.05	--	--	--	--	--
8	0.40	--	--	--	--	--
9	--	0.01	0.01	0.02	0.02	0.04
10	0.84	negl.	0.01	0.01	0.02	0.03
11	1.75*	--	--	--	--	--
	4.80	0.33	0.55	0.83	1.10	1.65

Region No.	Regional Total Supply*				
	(1)	(2)	(3)	(4)	(5)
1	0.01	0.01	0.02	0.02	0.03
2	0.52	0.55	0.58	0.62	0.70
3	0.17	0.20	0.23	0.26	0.31
4	0.62	0.73	0.87	1.01	1.28
5	0.42	0.45	0.48	0.51	0.58
6	0.34	0.35	0.38	0.40	0.44
7	0.05	0.05	0.05	0.05	0.05
8	0.40	0.40	0.40	0.40	0.40
9	0.01	0.01	0.02	0.02	0.04
10	0.84	0.85	0.85	0.86	0.87
11	1.75*	1.75*	1.75*	1.75*	1.75*
	5.13	5.35	5.63	5.90	6.45

Ø Before inclusion of abatement and Frasch S.
* Excluding Frasch sulfur.

APPENDIX 4

TABLE 28

PARAMETRIC CASES OF U.S. REGIONALIZED SUPPLY

- 1980

Region No.	Regional Supply Ø	Regional Abatement Supply				
		(1)	(3)	(5)	(6)	(7)
1	--	0.01	0.03	0.04	0.06	0.07
2	0.50	0.12	0.23	0.35	0.47	0.59
3	0.14	0.10	0.20	0.30	0.40	0.50
4	0.59	0.49	0.96	1.45	1.94	2.44
5	0.41	0.12	0.24	0.36	0.47	0.60
6	0.33	0.07	0.14	0.21	0.28	0.36
7	0.16	--	--	--	--	--
8	0.60	--	--	--	--	--
9	0.10	0.02	0.05	0.07	0.09	0.12
10	0.99	0.02	0.05	0.07	0.09	0.12
11	2.61	--	--	--	--	--
	6.43	0.95	1.90	2.85	3.80	4.80

Region No.	Regional Total Supply*				
	(1)	(3)	(5)	(6)	(7)
1	0.01	0.03	0.04	0.06	0.07
2	0.62	0.73	0.85	0.97	1.09
3	0.24	0.34	0.44	0.54	0.64
4	1.08	1.55	2.04	2.53	3.03
5	0.53	0.65	0.77	0.88	1.01
6	0.40	0.47	0.54	0.61	0.69
7	0.16	0.16	0.16	0.16	0.16
8	0.60	0.60	0.60	0.60	0.60
9	0.12	0.15	0.17	0.19	0.22
10	1.01	1.04	1.06	1.08	1.11
11	2.61*	2.61*	2.61*	2.61*	2.61*
	7.38	8.33	9.28	10.23	11.23

Ø Before inclusion of abatement and Frasch S.
* Excluding Frasch sulfur.

APPENDIX 4

TABLE 29

PARAMETRIC CASES OF U.S. REGIONALIZED SUPPLY

- 1985

Region No.	Regional Supply Ø	Regional Abatement Supply				
		(1)	(3)	(5)	(6)	(8)
1	0.10	0.02	0.03	0.04	0.05	0.07
2	0.63	0.16	0.28	0.38	0.55	0.76
3	0.14	0.15	0.26	0.36	0.52	0.72
4	0.82	0.78	1.30	1.82	2.60	3.64
5	0.43	0.19	0.31	0.44	0.62	0.87
6	0.45	0.11	0.18	0.25	0.37	0.51
7	0.17	--	--	--	--	--
8	0.80	--	--	--	--	--
9	0.10	0.04	0.06	0.09	0.12	0.18
10	1.27	0.05	0.08	0.12	0.17	0.25
11	2.88	--	--	--	--	--
	7.79	1.50	2.50	3.50	5.00	7.00

Region No.	Regional Total Supply*				
	(1)	(3)	(5)	(6)	(8)
1	0.12	0.13	0.14	0.15	0.17
2	0.79	0.91	1.01	1.18	1.39
3	0.29	0.40	0.50	0.66	0.86
4	1.60	2.12	2.64	3.42	4.46
5	0.62	0.74	0.87	1.05	1.30
6	0.56	0.63	0.70	0.82	0.96
7	0.17	0.17	0.17	0.17	0.17
8	0.80	0.80	0.80	0.80	0.80
9	0.14	0.16	0.19	0.22	0.28
10	1.32	1.35	1.39	1.44	1.52
11	2.88*	2.88*	2.88*	2.88*	2.88*
	9.29	10.29	11.29	12.79	14.79

Ø Before inclusion of abatement and Frasch S.
* Excluding Frasch sulfur.

APPENDIX 4

TABLE 30

PARAMETRIC CASES OF U.S. REGIONALIZED SUPPLY

- 1990

Region No.	Regional Supply ∅	Regional Abatement Supply				
		(1)	(4)	(6)	(7)	(9)
1	0.10	0.02	0.04	0.05	0.06	0.07
2	0.74	0.31	0.46	0.61	0.77	0.92
3	0.15	0.31	0.46	0.61	0.77	0.92
4	1.39	1.53	2.29	3.06	3.82	4.59
5	0.45	0.37	0.56	0.75	0.94	1.12
6	0.46	0.23	0.34	0.45	0.56	0.68
7	0.18	--	--	--	--	--
8	1.00	--	--	--	--	--
9	0.20	0.08	0.12	0.16	0.20	0.24
10	1.64	0.15	0.23	0.31	0.38	0.46
11	3.39	--	--	--	--	--
	9.70	3.0	4.5	6.0	7.5	9.0

Region No.	Regional Total Supply*				
	(1)	(4)	(6)	(7)	(9)
1	0.12	0.14	0.15	0.16	0.17
2	1.05	1.20	1.35	1.51	1.66
3	0.46	0.61	0.76	0.92	1.07
4	2.92	3.68	4.45	5.21	5.98
5	0.82	1.01	1.20	1.39	1.57
6	0.69	0.80	0.91	1.02	1.14
7	0.18	0.18	0.18	0.18	0.18
8	1.00	1.00	1.00	1.00	1.00
9	0.28	0.32	0.36	0.40	0.44
10	1.79	1.87	1.95	2.02	2.10
11	3.39*	3.39*	3.39*	3.39*	3.39*
	12.70	14.20	15.70	17.20	18.70

∅ Before inclusion of abatement and Frasch S.

* Excluding Frasch sulfur.

APPENDIX 4

TABLE 31

PARAMETRIC CASES OF U.S. REGIONALIZED SUPPLY

- 2000

Region No.	Regional Supply Ø	Regional Abatement Supply				
		(1)	(2)	(5)	(7)	(9)
1	0.10	0.02	0.03	0.04	0.05	0.06
2	1.08	0.48	0.72	0.96	1.20	1.44
3	0.15	0.46	0.68	0.91	1.14	1.37
4	2.92	2.54	3.81	5.08	6.35	7.62
5	0.49	0.62	0.94	1.25	1.56	1.88
6	0.68	0.38	0.56	0.75	0.94	1.12
7	0.29	--	--	--	--	--
8	1.70	--	--	--	--	--
9	0.30	0.14	0.22	0.29	0.36	0.43
10	2.77	0.36	0.54	0.72	0.90	1.08
11	4.25	--	--	--	--	--
	14.73	5.0	7.5	10.0	12.5	15.0

Region No.	Regional Total Supply*				
	(1)	(2)	(5)	(7)	(9)
1	0.12	0.13	0.14	0.15	0.16
2	1.56	1.80	2.04	2.28	2.52
3	0.61	0.83	1.06	1.29	1.52
4	5.46	6.73	8.00	9.27	10.54
5	1.11	1.43	1.74	2.05	2.37
6	1.06	1.24	1.43	1.62	1.80
7	0.29	0.29	0.29	0.29	0.29
8	1.70	1.70	1.70	1.70	1.70
9	0.44	0.52	0.59	0.66	0.73
10	3.13	3.31	3.49	3.67	3.85
11	4.25*	4.25*	4.25*	4.25*	4.25*
	19.73	22.23	24.73	27.33	29.73

Ø Before inclusion of abatement and Frasch S.
* Excluding Frasch sulfur.

APPENDIX 4

TABLE 32

PARAMETRIC CASES OF U.S. REGIONALIZED SUPPLY

- 2010

Region No.	Regional Supply Ø	Regional Abatement Supply (1)	(2)	(3)	(5)	(7)
1	0.20	--	--	--	--	--
2	1.53	1.09	1.26	1.44	1.62	1.80
3	0.26	0.92	1.08	1.23	1.39	1.54
4	4.92	6.20	7.24	8.27	9.30	10.34
5	0.64	1.50	1.75	2.00	2.25	2.50
6	0.91	0.96	1.12	1.28	1.44	1.60
7	0.41	--	--	--	--	--
8	2.60	--	--	--	--	--
9	0.40	0.36	0.42	0.48	0.54	0.60
10	4.12	0.97	1.13	1.30	1.46	1.62
11	6.00	--	--	--	--	--
	21.99	12.0	14.0	16.0	18.0	20.0

Region No.	Regional Total Supply* (1)	(2)	(3)	(5)	(7)
1	0.20	0.20	0.20	0.20	0.20
2	2.62	2.79	2.97	3.15	3.33
3	1.18	1.34	1.49	1.65	1.80
4	11.12	12.16	13.19	14.22	15.26
5	2.14	2.39	2.64	2.89	3.14
6	1.87	2.03	2.19	2.35	2.51
7	0.41	0.41	0.41	0.41	0.41
8	2.60	2.60	2.60	2.60	2.60
9	0.76	0.82	0.88	0.94	1.00
10	5.09	5.25	5.42	5.58	5.74
11	6.00*	6.00*	6.00*	6.00*	6.00*
	33.99	35.99	37.99	39.99	41.99

Ø Before inclusion of abatement and Frasch S.

* Excluding Frasch sulfur.

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TABLE 33

PARAMETRIC CASES OF U.S. REGIONALIZED SUPPLY

- 2020

Region No.	Regional Supply Ø	Regional Abatement Supply*				
		(0)	(1)	(2)	(3)	(4)
1	0.30	--	--	--	--	--
2	2.07	1.19	1.53	1.87	2.21	2.55
3	0.46	0.91	1.17	1.43	1.69	1.95
4	7.26	7.27	9.34	11.42	13.49	15.57
5	0.78	1.75	2.25	2.75	3.25	3.75
6	1.13	1.26	1.62	1.98	2.34	2.70
7	0.53	--	--	--	--	--
8	3.60	--	--	--	--	--
9	0.60	0.43	0.56	0.68	0.81	0.93
10	5.57	1.19	1.53	1.87	2.21	2.55
11	7.80	--	--	--	--	--
	30.10	14.0	18.0	22.0	26.0	30.0

Region No.	Regional Total Supply*				
	(0)	(1)	(2)	(3)	(4)
1	0.30	0.30	0.30	0.30	0.30
2	3.26	3.60	3.94	4.28	4.62
3	1.37	1.63	1.89	2.15	2.41
4	14.53	16.60	18.68	20.75	22.83
5	2.53	3.03	3.53	4.03	4.53
6	2.39	2.75	3.11	3.47	3.83
7	0.53	0.53	0.53	0.53	0.53
8	3.60	3.60	3.60	3.60	3.60
9	1.03	1.16	1.28	1.41	1.53
10	6.76	7.10	7.44	7.78	8.12
11	7.80*	7.80*	7.80*	7.80*	7.80*
	44.1	48.1	52.1	56.1	60.1

Ø Before inclusion of abatement and Frasch S.

* Excluding Frasch sulfur.

APPENDIX 4

TABLE 34

ASSUMPTIONS UNDERLYING RECOVERY OF ABATEMENT S IN USEFUL FORM

Year	Case	Million LT	(a)*		(b)*		(c)*		(d)*		(e)*	
			R	U	R	U	R	U	R	U	R	U
1975	1	0.33	NIL	30	-10	15	-20	10	30	8	-40	6
	2	0.55	NIL	50	-10	25	-20	17	-30	13	-40	10
	3	0.83	NIL	75	-10	38	-20	25	-30	19	-40	15
	4	1.10	NIL	100	-10	50	-20	33	-30	25	-40	20
	5	1.65	---	--	-10	75	-20	50	-30	38	-40	30
1980	1	0.95	NIL	50	-20	23	-40	15	-60	11	-80	9
	3	1.90	NIL	100	-20	46	-40	30	-60	22	-80	18
	5	2.85	---	--	-20	70	-40	45	-60	34	-80	27
	6	3.80	---	--	--	--	-40	60	-60	45	-80	36
	7	4.80	---	--	--	--	-40	76	-60	56	-80	45
1985	1	1.5	NIL	50	-20	29	-40	20	-50	16	-80	13
	3	2.5	NIL	83	-20	48	-40	34	-60	26	-80	21
	5	3.5	---	--	-20	67	-40	47	-60	36	-80	30
	6	5.0	---	--	-20	96	-40	68	-60	52	-80	42
	8	7.0	---	--	--	--	-40	95	-60	73	-80	59
1990	1	3.0	NIL	67	-20	45	-40	34	-60	27	-80	23
	4	4.5	NIL	100	-20	67	-40	51	-60	41	-80	34
	6	6.0	---	--	-20	90	-40	67	-60	54	-80	45
	7	7.5	---	--	--	--	-40	84	-60	68	-80	56
	0	9.0	---	--	--	--	--	--	-60	81	-80	68

APPENDIX 4

TABLE 34 (CONTINUED)

ASSUMPTIONS UNDERLYING RECOVERY OF ABATEMENT S IN USEFUL FORM

Year	Case	Million LT	(a)*		(b)*		(c)*		(d)*		(e)*	
			R	U	R	U	R	U	R	U	R	U
2000	1	5.0	NIL	54	-20	43	-40	36	-60	31	-71	29
	2	7.5	NIL	81	-20	65	-40	55	-60	47	-71	44
	5	10.0	---	--	-20	87	-40	73	-60	63	-71	58
	7	12.5	---	--	--	--	-40	91	-60	79	-71	73
	9	15.0	---	--	--	--	--	--	-60	94	-71	87
2010	1	12.0	NIL	69	-20	61	-40	55	-60	50	-61	49
	2	14.0	NIL	80	-20	71	-40	64	-60	58	-61	58
	3	16.0	NIL	92	-20	82	-40	73	-60	67	-61	66
	5	18.0	---	--	-20	92	-40	82	-60	75	-61	74
	7	20.0	---	--	--	--	-40	92	-60	83	-61	83
2020	0	14.0	NIL	48	-20	45	-40	42	-46	41	-70	38
	1	18.0	NIL	62	-20	57	-40	53	-46	52	-70	49
	2	22.0	NIL	75	-20	70	-40	65	-46	64	-70	59
	3	26.0	NIL	89	-20	83	-40	77	-46	76	-70	70
	5	30.0	---	--	--	--	--	--	-46	87	-70	81

* R = % reduction in total SO_x emitted by electric utilities from 1970 level (NIL is equivalent to abating the increment over the 1970 level).

U = % of abatement S recovered in useful form.

(a) through (e) represent different combinations of R and U that provide the same quantity of useful form S.

TABLE 35

HYPOTHETICAL COAL SULFUR CONTENTS REQUIRED TO GIVE TABLE 34 SO_x LEVELS WITHOUT CONTROLS

Million Lt of S Emitted by Electric Utilities	Average Wt % S in Utility Coal That, Without Any Abatement Control, Would Produce the SO_x Emission Levels Corresponding to the Cases in Table 34						
	1975	1980	1985	1990	2000	2010	2020
11.1	(1) 2.04	(1) 1.88	(1) 1.66	(1) 1.46	(1) 1.06	(1) 0.77	(0) 0.56
10.0	(2) 1.85						
8.9	(3) 1.65	(3) 1.50	(3) 1.33	(4) 1.17	(2) 0.85	(2) 0.62	(1) 0.45
7.8	(4) 1.44						
6.7	(5) 1.24	(5) 1.13	(5) 1.00	(6) 0.88	(5) 0.64	(3) 0.46	(2) 0.34
6.0							
4.5		(6) 0.76	(6) 0.67	(7) 0.59	(7) 0.43	(5) 0.31	(3) 0.30
4.3						(7) 0.30	
3.3							(5) 0.17
3.2					(9) 0.30		
2.3		(7) 0.39	(8) 0.34	(9) 0.30			

Note: Figures in parentheses refer to the case numbers in Table 34.

APPENDIX 4

TABLE 36

PARAMETRIC CASES OF U.S. REGIONALIZED DEMAND AND NET SUPPLY/DEMAND POSITION

- 1975

Region No.	Demand Base	Regional Demand Minus Regional Supply* Base	(1)	(2)	(3)	(4)	(5)
1	0.08	0.08	0.07	0.07	0.06	0.06	0.05
2	1.02	0.55	0.50	0.47	0.44	0.40	0.32
3	1.04	0.90	0.87	0.84	0.81	0.78	0.73
4	1.30	0.84	0.68	0.57	0.43	0.29	0.02
5	0.70	0.32	0.28	0.25	0.22	0.19	0.12
6	0.47	0.16	0.13	0.12	0.09	0.07	0.03
7	0.30	0.25	0.25	0.25	0.25	0.25	0.25
8	0.61	0.21	0.21	0.21	0.21	0.21	0.21
9	2.54	2.54	2.53	2.53	2.52	2.52	2.50
10	0.96	0.12	0.12	0.11	0.11	0.10	0.09
11	2.56	0.81	0.81	0.81	0.81	0.81	0.81
	11.58	+6.78	+6.45	+6.23	+5.95	+5.68	+5.13

Region No.	1.05 x Base	Regional Demand Minus Regional Supply* 1.05 x B	(1)	(2)	(3)	(4)	(5)
1	0.08	0.08	0.07	0.07	0.06	0.06	0.05
2	1.07	0.60	0.55	0.52	0.49	0.45	0.37
3	1.09	0.95	0.92	0.89	0.86	0.83	0.78
4	1.37	0.91	0.75	0.64	0.50	0.26	0.09
5	0.74	0.36	0.32	0.29	0.26	0.23	0.16
6	0.49	0.18	0.15	0.14	0.11	0.09	0.05
7	0.31	0.26	0.26	0.26	0.26	0.26	0.26
8	0.64	0.24	0.24	0.24	0.24	0.24	0.24
9	2.67	2.67	2.66	2.66	2.85	2.65	2.63
10	1.01	0.17	0.17	0.17	0.16	0.15	0.14
11	2.69	0.94	0.94	0.94	0.94	0.94	0.94
	12.16	+7.36	+7.03	+6.81	+6.53	+6.16	+5.71

* Excluding Frasch Sulfur

APPENDIX 4

TABLE 37

PARAMETRIC CASES OF U.S. REGIONALIZED DEMAND AND NET SUPPLY/DEMAND POSITION

o 1980

Region No.	Demand Base	Regional Demand Minus Regional Supply* Base	(1)	(3)	(5)	(6)	(7)
1	0.08	0.08	0.07	0.05	0.04	0.02	0.01
2	1.09	0.59	0.47	0.36	0.24	0.12	Nil
3	1.05	0.91	0.81	0.71	0.61	0.51	0.41
4	1.66	1.07	0.58	0.11	-0.38	-0.87	-1.37
5	0.79	0.38	0.26	0.14	0.02	-0.09	-0.22
6	0.54	0.21	0.14	0.07	Nil	-0.07	-0.15
7	0.36	0.20	0.20	0.20	0.20	0.20	0.20
8	0.74	0.14	0.14	0.14	0.14	0.14	0.14
9	3.19	3.09	3.07	3.04	3.02	3.00	2.97
10	1.26	0.27	0.25	0.22	0.20	0.18	0.15
11	3.00	0.39	0.39	0.39	0.39	0.39	0.39
	13.76	+7.33	+6.38	+5.43	+4.86	+4.56	+4.27
		- ..	- ..	- ..	-0.38	-1.03	-1.74

Region No.	1.05 x Base	1.05 x B	(1)	(3)	(5)	(6)	(7)
1	0.09	0.09	0.08	0.06	0.05	0.03	0.02
2	1.14	0.64	0.52	0.41	0.29	0.17	0.05
3	1.10	0.96	0.86	0.76	0.66	0.56	0.46
4	1.74	1.15	0.66	0.19	-0.30	-0.79	-1.29
5	0.83	0.42	0.30	0.18	0.06	-0.05	-0.18
6	0.57	0.24	0.17	0.10	0.03	-0.04	-0.12
7	0.38	0.22	0.22	0.22	0.22	0.22	0.22
8	0.78	0.18	0.18	0.18	0.18	0.18	0.18
9	3.35	3.25	3.23	3.20	3.18	3.16	3.13
10	1.32	0.33	0.31	0.28	0.26	0.24	0.21
11	3.15	0.54	0.54	0.54	0.54	0.54	0.54
	14.45	+8.02	+7.07	+6.12	+5.47	+5.10	+4.81
		- ..	- ..	- ..	-0.30	-0.88	-1.59

* Excluding Frasch sulfur

(Cont'd)

TABLE 37
(Cont'd)

Region No.	1.10 x Base	Regional Demand Minus Regional Supply*					
		1.10 x B	(1)	(3)	(5)	(6)	(7)
1	0.09	0.09	0.08	0.06	0.05	0.03	0.02
2	1.20	0.70	0.58	0.47	0.35	0.23	0.11
3	1.15	1.01	0.91	0.81	0.71	0.61	0.51
4	1.83	1.24	0.75	0.28	-0.21	-0.70	-1.20
5	0.87	0.46	0.34	0.22	0.10	-0.01	-0.14
6	0.59	0.26	0.19	0.12	0.05	-0.02	-0.10
7	0.40	0.24	0.24	0.24	0.24	0.24	0.24
8	0.81	0.21	0.21	0.21	0.21	0.21	0.21
9	3.51	3.41	3.39	3.36	3.34	3.32	3.29
10	1.39	0.40	0.38	0.35	0.33	0.31	0.28
11	3.30	0.69	0.69	0.69	0.69	0.69	0.69
	15.14	+8.71	+7.76	+6.81	+6.07	+5.64	+5.35
		- ..	- ..	- ..	-0.21	-0.73	-1.44

* Excluding Frasch sulfur

NOTE: The net regional demands (+) may not be offset with net regional surplusses (-), hence the U.S. totals for these quantities are summed separately.

APPENDIX 4

TABLE 38

PARAMETRIC CASES OF U.S. REGIONALIZED DEMAND AND NET SUPPLY/DEMAND POSITION

- 1985

Region No.	Demand Base	Regional Demand Minus Regional Supply*					
		Base	(1)	(3)	(5)	(6)	(8)
1	0.08	-0.02	-0.04	-0.05	-0.06	-0.07	-0.09
2	1.25	0.62	0.46	0.34	0.24	0.07	-0.14
3	1.20	1.06	0.91	0.80	0.70	0.54	0.34
4	2.07	1.25	0.47	-0.05	-0.57	-1.35	-2.39
5	0.94	0.51	0.32	0.20	0.07	-0.11	-0.36
6	0.65	0.20	0.07	0.02	-0.05	-0.17	-0.31
7	0.44	0.27	0.27	0.27	0.27	0.27	0.27
8	0.91	0.11	0.11	0.11	0.11	0.11	0.11
9	3.54	3.44	3.40	3.38	3.35	3.32	3.26
10	1.65	0.38	0.33	0.30	0.26	0.21	0.13
11	3.43	0.55	0.55	0.55	0.55	0.55	0.55
	16.16	+8.39	+6.91	+5.97	+5.55	+5.07	+4.66
		-0.02	-0.04	-0.10	-0.68	-1.70	-3.29

Region No.	1.05 x Base	1.05 x B	(1)	(3)	(5)	(6)	(8)
1	0.09	-0.01	-0.03	-0.04	-0.05	-0.06	-0.08
2	1.31	0.68	0.52	0.40	0.30	0.13	-0.08
3	1.26	1.12	0.97	0.86	0.76	0.60	0.40
4	2.17	1.35	0.57	0.05	-0.47	-1.25	-2.29
5	0.99	0.56	0.37	0.25	0.12	-0.06	-0.31
6	0.68	0.23	0.13	0.05	-0.02	-0.14	-0.28
7	0.46	0.29	0.29	0.29	0.29	0.29	0.29
8	0.36	0.16	0.16	0.16	0.16	0.16	0.16
9	3.72	3.62	3.58	3.56	3.53	3.50	3.44
10	1.73	0.46	0.41	0.38	0.34	0.29	0.21
11	3.60	0.72	0.72	0.72	0.72	0.72	0.72
	16.97	+9.19	+7.72	+6.72	+6.22	+5.09	+5.22
		-0.01	-0.03	-0.04	-0.54	-1.51	-3.04

* Excluding Frasch sulfur

TABLE 38
(Cont'd)

Region No.	1.10 x Base	Regional Demand Minus Regional Supply*					
		1.10 x B	(1)	(3)	(5)	(6)	(8)
1	0.09	-0.01	-0.03	-0.04	-0.05	-0.06	-0.08
2	1.38	0.75	0.59	0.47	0.28	0.20	-0.01
3	1.32	1.18	1.03	0.92	0.82	0.66	0.46
4	2.28	1.46	0.68	0.16	-0.36	-1.14	-2.18
5	1.03	0.60	0.41	0.29	0.16	-0.02	-0.27
6	0.72	0.27	0.16	0.09	0.02	-0.10	-0.24
7	0.48	0.31	0.31	0.31	0.31	0.31	0.31
8	1.00	0.20	0.20	0.20	0.20	0.20	0.20
9	3.89	3.79	3.75	3.73	3.70	3.67	3.61
10	1.82	0.55	0.50	0.47	0.43	0.38	0.30
11	3.77	0.89	0.89	0.89	0.89	0.89	0.89
	17.78	+10.00	+8.52	+7.53	+6.81	+6.31	+5.77
		- 0.01	-0.03	-0.04	-0.41	-1.32	-2.78

* Excluding Frasch sulfur

NOTE: The net regional demands (+) may not be offset with net regional surplusses (-), hence the U.S. totals for these quantities are summed separately.

APPENDIX 4

TABLE 39

PARAMETRIC CASES OF U.S. REGIONALIZED DEMAND AND NET SUPPLY/DEMAND POSITION

- 1990

Region No.	Demand Base	Regional Demand Minus Regional Supply*					
		Base	(1)	(4)	(6)	(7)	(9)
1	0.10	Nil	-0.02	-0.04	-0.05	-0.06	-0.07
2	1.47	0.73	0.42	0.27	0.12	-0.04	-0.19
3	1.42	1.27	0.96	0.81	0.66	0.50	0.35
4	2.51	1.12	-0.41	-1.17	-1.94	-2.70	-3.47
5	1.10	0.65	0.28	0.09	-0.10	-0.29	-0.47
6	0.78	0.32	0.09	-0.02	-0.13	-0.24	-0.36
7	0.53	0.35	0.35	0.35	0.35	0.35	0.35
8	1.14	0.14	0.14	0.14	0.14	0.14	0.14
9	3.80	3.60	3.52	3.48	3.44	3.40	3.36
10	2.23	0.59	0.44	0.36	0.28	0.21	0.13
11	3.90	0.51	0.51	0.51	0.51	0.51	0.51
	18.98	+9.28	+6.71	+6.01	+5.50	+5.11	+4.84
		- ..	-0.43	-1.23	-2.22	-3.33	-4.56

Region No.	1.05 x Base	1.05 x B	(1)	(4)	(6)	(7)	(9)
1	0.11	0.01	-0.01	-0.03	-0.04	-0.05	-0.06
2	1.54	0.80	0.49	0.34	0.19	0.03	-0.12
3	1.49	1.34	1.03	0.88	0.73	0.57	0.42
4	2.63	1.24	-0.29	-1.05	-1.82	-2.58	-3.35
5	1.16	0.71	0.34	0.15	-0.04	-0.23	-0.41
6	0.82	0.36	0.13	0.02	-0.09	-0.20	-0.32
7	0.56	0.38	0.38	0.38	0.38	0.38	0.38
8	1.20	0.20	0.20	0.20	0.20	0.20	0.20
9	3.99	3.79	3.71	3.67	3.63	3.59	3.55
10	2.34	0.70	0.55	0.47	0.39	0.32	0.24
11	4.09	0.70	0.70	0.70	0.70	0.70	0.70
	19.93	+10.23	+7.53	+6.81	+6.22	+5.79	+5.49
		- ..	-0.30	-1.08	-1.99	-3.06	-4.26

* Excluding Frasch sulfur

TABLE 39
(Cont'd)

Region No.	1.10 x Base	Regional Demand Minus Regional Supply*					
		1.10 x B	(1)	(4)	(6)	(7)	(9)
1	0.11	0.01	-0.01	-0.03	-0.04	-0.05	-0.06
2	1.62	0.88	0.57	0.42	0.27	0.11	-0.04
3	1.56	1.41	1.10	0.95	0.80	0.64	0.49
4	2.76	1.37	-0.16	-0.92	-1.69	-2.45	-3.22
5	1.21	0.76	0.39	0.20	0.01	-0.18	-0.36
6	0.86	0.40	0.17	0.06	-0.05	-0.16	-0.28
7	0.58	0.40	0.40	0.40	0.40	0.40	0.40
8	1.25	0.25	0.25	0.25	0.25	0.25	0.25
9	4.18	3.98	3.90	3.86	3.82	3.78	3.74
10	2.45	0.81	0.66	0.58	0.50	0.43	0.35
11	4.29	0.90	0.90	0.90	0.90	0.90	0.90
	20.87	+11.17	+8.34	+7.62	+6.95	+6.51	+6.13
		- ..	-0.17	-0.95	-1.78	-2.84	-3.96

* Excluding Frasch sulfur

NOTE: The net regional demands (+) may not be offset with net regional surplusses (-), hence the U.S. totals for these quantities are summed separately.

APPENDIX 4

TABLE 40

PARAMETRIC CASES OF U.S. REGIONALIZED DEMAND AND NET SUPPLY/DEMAND POSITION

- 2000

Region No.	Demand Base	Regional Demand Minus Regional Supply* Base	(1)	(2)	(5)	(7)	(9)
1	0.14	0.04	0.02	0.01	Nil	-0.01	-0.02
2	2.01	0.93	0.45	0.21	0.03	-0.27	-0.51
3	1.90	1.75	1.29	1.07	0.84	0.61	0.38
4	3.53	0.61	-1.93	-3.20	-4.47	-5.74	-7.01
5	1.54	1.05	0.43	0.11	-0.20	-0.51	-0.83
6	1.04	0.36	-0.02	-0.20	-0.39	-0.58	-0.76
7	0.78	0.49	0.49	0.49	0.49	0.49	0.49
8	1.68	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
9	4.20	3.90	3.76	3.68	3.61	3.54	3.47
10	3.51	0.74	0.38	0.20	0.02	-0.16	-0.34
11	4.90	0.65	0.65	0.65	0.65	0.65	0.65
	25.23	+10.52	+7.47	+6.42	+5.61	+5.29	+4.99
		- 0.02	-1.97	-3.42	-5.11	-7.29	-9.49

Region No.	1.05 x Base	1.05 x B	(1)	(2)	(5)	(7)	(8)
1	0.15	0.05	0.03	0.02	0.01	Nil	-0.01
2	2.11	1.03	0.55	0.31	0.07	-0.17	-0.41
3	2.00	1.85	1.39	1.17	0.94	0.71	0.48
4	3.71	0.79	-1 75	-3.02	-4.29	-5.56	-6.83
5	1.62	1.13	0.51	0.19	-0.12	-0.43	-0.75
6	1.09	0.41	0.03	-0.15	-0.34	-0.53	-0.71
7	0.82	0.53	0.53	0.53	0.53	0.53	0.53
8	1.76	0.06	0.06	0.06	0.06	0.06	0.06
9	4.41	4.11	3.97	3.89	3.82	3.75	3.68
10	3.68	0.91	0.55	0.37	0.19	0.01	0.17
11	5.14	0.89	0.89	0.89	0.89	0.89	0.89
	26.49	+11.76	+8.51	+7.43	+6.51	+5.95	+5.64
		- ..	-1.75	-3.17	-4.75	-6.69	-8.88

* Excluding Frasch sulfur

TABLE 40
(Cont'd)

Region		Regional Demand Minus Regional Supply*					
No.	1.10 x Base	1.10 x B	(1)	(2)	(5)	(7)	(8)
1	0.15	0.05	0.03	0.02	0.01	Nil	-0.01
2	2.21	1.13	0.65	0.41	0.17	-0.07	-0.31
3	2.09	1.94	1.48	1.26	1.03	0.80	0.57
4	3.88	0.96	-1.58	-2.85	-4.12	-5.39	-6.66
5	1.69	1.20	0.58	0.26	-0.05	-0.36	-0.68
6	1.14	0.46	0.08	-0.07	-0.29	-0.48	-0.66
7	0.86	0.57	0.57	0.57	0.57	0.57	0.57
8	1.85	0.15	0.15	0.15	0.15	0.15	0.15
9	4.62	4.32	4.18	4.10	4.03	3.96	3.89
10	3.86	1.09	0.73	0.55	0.37	0.19	0.01
11	5.40	1.15	1.15	1.15	1.15	1.15	1.15
	27.75	+13.02	+9.60	+8.47	+7.48	+6.82	+6.34
		- ..	-1.58	-2.92	-4.46	-6.30	-8.32

* Excluding Frasch sulfur

NOTE: The net regional demands (+) may not be offset with net regional surplusses (-), hence the U.S. totals for these quantities are summed separately.

APPENDIX 4

TABLE 41

PARAMETRIC CASES OF U.S. REGIONALIZED DEMAND AND NET SUPPLY/DEMAND POSITION

- 2010

Region No.	Demand Base	Regional Demand Minus Regional Supply* Base	(1)	(2)	(3)	(5)	(7)
1	0.18	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
2	2.70	1.17	0.08	-0.09	-0.27	-0.45	-0.63
3	2.50	2.24	1.32	1.16	1.01	0.85	0.70
4	4.89	-0.03	-6.23	-7.27	-8.30	-9.33	-10.37
5	2.10	1.46	-0.04	-0.29	-0.54	-0.79	-1.04
6	1.41	0.50	-0.40	-0.62	-0.78	-0.94	-1.10
7	1.11	0.70	0.70	0.70	0.70	0.70	0.70
8	2.43	-0.17	-0.17	-0.17	-0.17	-0.17	-0.17
9	4.48	4.08	3.72	3.66	3.60	3.54	3.48
10	5.00	0.88	-0.09	-0.25	-0.42	-0.58	-0.74
11	6.15	0.15	0.15	0.15	0.15	0.15	0.15
	32.95	+11.18	+5.97	+5.67	+ 5.46	+ 5.24	+ 5.03
		- 0.22	-7.01	-8.71	-10.50	-12.28	-14.07

Region No.	1.10 x Base	1.10 x B	(1)	(2)	(3)	(5)	(7)
1	0.20	Nil	Nil	Nil	Nil	Nil	Nil
2	2.97	1.44	0.35	0.18	Nil	-0.18	-0.36
3	2.75	2.49	1.57	1.41	1.26	1.10	0.95
4	5.38	0.46	-5.74	-6.78	-7.81	-8.84	-9.88
5	2.31	1.67	0.17	-0.08	-0.33	-0.58	-0.83
6	1.58	0.64	-0.32	-0.48	-0.64	-0.80	-0.96
7	1.22	0.81	0.81	0.81	0.81	0.81	0.81
8	2.67	0.07	0.07	0.07	0.07	0.07	0.07
9	4.93	4.53	4.17	4.11	4.05	3.99	3.93
10	5.50	1.38	0.41	0.25	0.08	-0.08	-0.24
11	6.77	0.77	0.77	0.77	0.77	0.77	0.77
	36.25	+14.26	+8.32	+7.60	+7.04	+ 6.74	+ 6.53
		- ..	-6.06	-7.34	-8.78	-10.48	-12.27

* Excluding Frasch sulfur

TABLE 41
(Cont'd)

Region No.	1.15 x Base	Regional Demand Minus Regional Supply* 1.15 x B	(1)	(2)	(3)	(5)	(7)
1	0.21	0.01	0.01	0.01	0.01	0.01	0.01
2	3.11	1.58	0.49	0.32	0.14	-0.04	-0.22
3	2.88	2.62	1.70	1.54	1.39	1.23	1.08
4	5.62	0.70	-5.50	-6.54	-7.57	-8.60	-9.64
5	2.41	1.77	0.27	0.02	-0.23	-0.48	-0.73
6	1.62	0.71	-0.25	-0.41	-0.57	-0.73	-0.89
7	1.28	0.87	0.87	0.87	0.87	0.87	0.87
8	2.79	0.19	0.19	0.19	0.19	0.19	0.19
9	5.15	4.75	4.39	4.33	4.27	4.21	4.15
10	5.75	1.63	0.66	0.50	0.33	0.17	0.01
11	7.07	1.07	1.07	1.07	1.07	1.07	1.07
	37.89	+15.90	+9.65	+8.85	+8.27	+7.75	+ 7.38
		- ..	-5.72	-6.95	-8.37	-9.85	-11.48

* Excluding Frasch sulfur

NOTE: The net regional demands (+) may not be offset with net regional surplusses (-), hence the U.S. totals for these quantities are summed separately.

APPENDIX 4

TABLE 42

PARAMETRIC CASES OF U.S. REGIONALIZED DEMAND AND NET SUPPLY/DEMAND POSITION

- 2020

Region No.	Demand Base	Regional Demand Minus Regional Supply* Base	(0)	(1)	(2)	(3)	(4)
1	0.25	0.05	0.05	0.05	0.05	0.05	0.05
2	3.59	1.52	0.33	0.01	0.35	0.69	1.03
3	3.24	2.78	1.87	1.61	1.35	1.09	0.83
4	6.51	0.75	8.02	10.09	12.17	14.24	16.32
5	2.87	2.09	0.34	0.16	0.66	1.16	1.66
6	1.83	0.70	0.56	0.92	1.28	1.64	2.00
7	1.56	1.03	1.03	1.03	1.03	1.03	1.03
8	3.39	0.21	0.21	0.21	0.21	0.21	0.21
9	4.69	4.09	3.66	3.53	3.41	3.28	3.16
10	6.69	1.12	0.07	0.41	0.75	1.09	1.43
11	7.77	0.03	0.03	0.03	0.03	0.03	0.03
	42.39	+13.30	+7.20	+ 6.14	+ 5.76	+ 5.37	+ 4.99
		- 1.04	-8.94	-11.88	-15.50	-19.11	-22.73

Region No.	1.15 x Base	1.15 x B	(0)	(1)	(2)	(3)	((4)
1	0.29	-0.01	-0.01	0.01	-0.01	-0.01	-0.01
2	4.13	2.06	0.87	0.53	0.19	-0.15	-0.49
3	3.73	3.27	2.36	2.10	1.84	1.58	1.32
4	7.49	0.23	-7.04	-9.11	-11.20	-13.26	-15.34
5	3.30	2.52	0.77	0.27	-0.23	-0.73	-1.23
6	2.10	0.97	-0.29	-0.65	-1.10	-1.37	-1.73
7	1.79	1.26	1.26	1.26	1.26	1.26	1.26
8	3.90	0.30	0.30	0.30	0.30	0.30	0.30
9	5.39	4.79	4.36	4.23	4.11	3.98	3.86
10	7.69	2.12	0.93	0.59	0.25	0.09	-0.43
11	8.94	1.14	1.14	1.14	1.14	1.14	1.14
	48.75	+18.66	+11.99	+10.42	+ 9.09	+ 8.26	+ 7.88
		- 0.01	- 7.34	- 9.77	-12.45	-15.61	-19.23

* Excluding Frasch sulfur

TABLE 42
(Cont'd)

Region No.	1.30 x Base	1.30 x B	(0)	(1)	(2)	(3)	(4)
1	0.33	0.03	0.03	0.03	0.03	0.03	0.03
2	4.67	2.60	1.41	1.07	0.73	0.39	0.05
3	4.21	3.75	2.84	2.58	2.32	2.06	1.80
4	8.46	1.20	-6.07	-8.14	-10.23	-12.29	-14.37
5	3.73	2.95	1.29	0.70	0.20	-0.30	-0.80
6	2.38	1.25	-0.01	-0.37	-0.73	-1.09	-1.45
7	2.03	1.50	1.50	1.50	1.50	1.50	1.50
8	4.41	0.81	0.81	0.81	0.81	0.81	0.81
9	6.10	5.50	5.07	4.94	4.82	4.69	4.57
10	8.69	3.12	1.93	1.59	1.25	0.91	0.57
11	10.10	2.30	2.30	2.30	2.30	2.30	2.30
	55.11	+25.01	+17.09	+15.52	+13.96	+12.69	+11.63
		- ..	- 6.08	- 8.51	-10.96	-13.68	-16.62

* Excluding Frasch sulfur

NOTE: The net regional demands (+) may not be offset with net regional surplusses (-), hence the U.S. totals for these quantities are summed separately.

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TABLE 43

FOREIGN SUPPLY PROJECTIONS BY GEOGRAPHICAL AREA
(Million LT of S Equivalent)

	1970	1975	1980	1985	1990	2000	2010	2020
• Canada								
Natural Gas	4.10	7.0	8.0	7.2	4.5	0.5	0.4	0.3
Petroleum	0.05	0.05	0.1	0.2	0.3	0.6	1.2	1.8
Smelter/Pyrite	0.60	1.5	3.6	4.3	5.0	6.0	7.0	8.0
Other	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1
	4.80	8.6	11.8	11.8	9.9	7.2	8.7	10.2
• Japan								
Petroleum	0.20	0.7	1.5	2.5	4.4	8.1	11.9	16.4
Smelter/Pyrite	2.60	3.3	3.7	3.3	3.0	3.0	3.0	3.0
Other	0.40	0.2	0.2	0.3	0.3	0.3	0.3	0.4
	3.20	4.2	5.4	6.1	7.7	11.4	15.2	19.8
• W. Europe								
Natural Gas	1.70	1.9	2.0	2.0	1.5	1.1	0.8	0.5
Petroleum	0.25	0.8	2.5	5.1	8.0	14.0	21.4	31.0
Smelter/Pyrite	5.25	5.3	5.2	4.7	4.2	3.5	3.4	3.4
Other	1.20	1.3	1.3	1.4	1.6	1.6	1.6	1.6
	8.40	9.3	11.0	13.2	15.3	20.2	27.2	36.5
• Latin America								
Frasch	1.35	1.1	1.3	1.5	1.7	2.0	1.2	0.7
Natural Gas	--	--	--	0.1	0.1	0.1	0.1	0.1
Petroleum	0.20	0.9	1.2	1.8	2.5	4.5	7.5	11.5
Smelter/Pyrite	0.10	0.2	0.3	0.5	0.7	0.9	1.2	1.8
Other	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.5
	1.70	2.3	2.9	4.1	5.2	7.8	10.4	14.6
• Africa								
Natural Gas	--	0.1	0.1	0.2	0.3	0.3	0.2	0.2
Petroleum	0.10	0.1	0.2	0.3	0.4	0.6	0.9	1.3
Smelter/Pyrite	0.50	0.5	0.6	0.6	0.7	0.7	0.8	1.0
Other	--	--	--	0.1	0.1	0.1	0.1	0.1
	0.60	0.7	0.9	1.2	1.5	1.7	2.0	2.6
• Middle E./Far E.								
Frasch	--	--	0.5	0.5	0.5	0.5	0.5	0.5
Natural Gas	0.20	0.4	0.4	1.1	1.5	1.5	1.2	0.9
Petroleum	0.25	0.5	0.9	1.5	3.0	7.5	12.9	20.0
Smelter/Pyrite	0.20	0.3	0.5	0.7	1.0	1.5	2.0	2.7
Other	0.05	0.1	0.1	0.2	0.2	0.3	0.3	0.4
	0.70	1.3	2.4	4.0	6.2	11.3	16.8	25.1
Total (F.W. ex U.S.)	19.4	26.4	34.4	40.4	45.8	59.6	80.3	108.8

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TABLE 44

FOREIGN SUPPLY PROJECTIONS BY SOURCE OF SULFUR (MILLION LT OF S EQUIVALENT)

• Frasch	1970	1975	1980	1985	1990	2000	2010	2020
Latin America	1.35	1.1	1.3	1.5	1.7	2.0	1.2	0.7
Middle East	--	--	0.5	0.5	0.5	0.5	0.5	0.5
	1.35	1.1	1.8	2.0	2.2	2.5	1.7	1.2
• Natural Gas								
Canada	4.10	7.0	8.0	7.2	4.5	0.5	0.4	0.3
W. Europe	1.70	1.9	2.0	2.0	1.5	1.1	0.8	0.5
Latin America	--	--	--	0.1	0.1	0.1	0.1	0.1
Africa	--	0.1	0.0	0.2	0.3	0.3	0.2	0.2
M.E./F.E.	0.20	0.4	0.4	1.1	1.5	1.5	1.2	0.9
	6.00	9.4	10.5	10.6	7.9	3.5	2.7	2.0
• Petroleum								
Canada	0.05	0.05	0.1	0.2	0.3	0.6	1.2	1.8
Japan	0.20	0.7	1.5	2.5	4.4	8.1	11.9	16.4
W. Europe	0.25	0.8	2.5	5.1	8.0	14.0	21.4	31.0
Latin America	0.20	0.9	1.2	1.8	2.5	4.5	7.5	11.5
Africa	0.10	0.1	0.2	0.3	0.4	0.6	0.9	1.3
M.E./F.E.	0.25	0.5	0.9	1.5	3.0	7.5	12.8	20.6
	1.05	3.05	6.4	11.4	18.6	35.3	55.7	82.6
• Smelter/Pyrite								
Canada	0.60	1.5	3.6	4.3	5.0	6.0	7.0	8.0
Japan	2.60	3.3	3.7	3.3	3.0	3.0	3.0	3.0
W. Europe	5.25	5.3	5.2	4.7	4.2	3.5	3.4	3.4
Latin America	0.10	0.2	0.3	0.5	0.7	0.9	1.2	1.8
Africa	0.50	0.5	0.6	0.6	0.7	0.7	0.8	1.0
M.E./F.E.	0.20	0.3	0.5	0.7	1.0	1.5	2.0	2.7
	9.25	11.1	13.9	14.1	14.6	15.6	17.4	19.9
• Other								
Canada	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1
Japan	0.40	0.2	0.2	0.3	0.3	0.3	0.3	0.4
W. Europe	1.20	1.3	1.3	1.4	1.6	1.6	1.6	1.6
Latin America	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4
M.E /F.E.	0.05	0.1	0.1	0.2	0.2	0.3	0.3	0.4
	1.75	1.75	1.8	2.3	2.5	2.7	2.8	3.1
Total (F.W. ex U.S.)	19.4	26.4	34.4	40.4	45.8	59.6	80.3	108.8

APPENDIX 4

TABLE 45

FOREIGN SUPPLY/DEMAND BALANCES
(MILLION LT OF S EQUIVALENT)

• Canada	1970	1975	1980	1985	1990	2000	2010	2020
Indust. Demand	0.7	0.8	0.9	1.0	1.2	1.9	2.7	3.9
Fert. Demand	0.5	0.6	0.8	1.0	1.3	1.7	2.2	2.8
(A)Total Demand	1.2	1.4	1.7	2.0	2.5	3.6	4.9	6.7
(B)Supply	4.8	8.6	11.8	11.8	9.9	7.2	8.7	10.2
(B)-(A)	3.6	7.2	10.1	9.8	7.4	3.6	3.8	3.5
• Japan								
Indust. Demand	1.2	1.8	2.9	3.8	5.2	8.0	11.1	14.7
Fert. Demand	1.1	1.3	1.5	1.6	1.7	1.8	2.0	2.1
(A)Total Demand	2.3	3.1	4.4	5.4	6.9	9.8	13.1	16.8
(B)Supply	3.2	4.2	5.4	6.1	7.7	11.4	15.2	19.8
(B)-(A)	0.9	1.1	1.0	0.7	0.8	1.6	2.1	3.0
• W. Europe								
Indust. Demand	5.5	6.4	7.2	8.7	10.5	14.7	20.6	28.4
Fert. Demand	4.9	5.4	5.9	6.4	7.1	8.6	10.2	12.0
(A)Total Demand	10.4	11.8	13.1	15.1	17.6	23.3	30.8	40.4
(B)Supply	8.4	9.3	11.0	13.2	15.3	20.2	27.2	36.5
(B)-(A)	-2.0	-2.5	-2.1	-1.9	-2.3	-3.1	-3.6	-3.9
• Latin America								
Indust. Demand	0.6	1.0	1.5	2.0	2.6	4.1	6.5	9.9
Fert. Demand	0.6	1.0	1.7	2.5	3.3	5.4	7.7	10.4
(A)Total Demand	1.2	2.0	3.2	4.5	5.9	9.5	14.2	20.3
(B)Supply	1.7	2.3	2.9	4.1	5.2	7.8	10.4	14.6
(B)-(A)	0.5	0.3	-0.3	-0.4	-0.7	-1.7	-3.8	-5.7
• Africa								
Indust. Demand	0.4	0.6	0.8	1.0	1.2	1.8	2.8	3.9
Fert. Demand	0.7	0.9	1.1	1.3	1.5	2.0	2.6	3.2
(A)Total Demand	1.1	1.5	1.9	2.3	2.7	3.8	5.4	7.1
(B)Supply	0.6	0.7	0.9	1.2	1.5	1.7	2.0	2.6
(B)-(A)	-0.5	-0.8	-1.0	-1.1	-1.2	-2.1	-3.4	-4.5
• Middle E./Far E.								
Indust. Demand	1.1	1.7	2.5	3.4	4.4	7.1	11.4	17.9
Fert. Demand	1.7	2.8	4.5	5.9	7.6	11.2	15.4	19.8
(A)Total Demand	2.8	4.5	7.0	9.3	12.0	18.3	26.8	37.7
(B)Supply	0.7	1.3	2.4	4.0	6.2	11.3	16.8	25.1
(B)-(A)	-2.1	-3.2	-4.6	-5.3	-5.8	-7.0	-10.0	-12.6
Total (F.W. ex U.S)								
(A) Total Demand	19.0	24.3	31.3	38.6	47.6	68.3	95.2	129.0
(B) Supply	19.4	26.4	34.4	40.4	45.8	59.6	80.3	108.8
(B)-(A)	0.4	2.1	3.1	1.6	-1.8	-8.7	-14.9	-20.2

APPENDIX 4

TABLE 46

COMMUNIST BLOC D/S BALANCES AND PROJECTED NET EXPORTS

(MILLION LT)

	1970	1975	1980	1985	1990	2000	2010	2020
Supply (A)	11.1	14.7	19.2	22.7	25.5	31.7	39.7	51.2
Demand (B)	9.3	12.4	16.2	19.9	24.3	34.7	48.3	65.6
(A) - (B)	1.8	2.3	3.0	2.8	1.2	-3.0	-8.6	-14.4
Projected Net Exports To F.W.								
	1.5	1.7	1.8	1.8	1.3	NIL	NIL	NIL
Projected Destination of Net Exports								
W. Europe	0.7	0.7	0.5	0.5	0.5			
Africa	0.2	0.3	0.3	0.3	0.2			
M.E./F.E.	0.4	0.5	0.8	0.8	0.5			
Lat. America	0.2	0.2	0.2	0.2	0.1			

APPENDIX 4

TABLE 47

FOREIGN COMPONENTS OF NORTH AMERICAN MODEL D/S BALANCE

(MILLION LT OF S EQUIVALENT)

	1970	1975	1980	1985	1990	2000	2010	2020
Potential Supply*								
W. Canadian (el. S)	4.1	7.0	8.0	7.2	4.5	0.5	0.4	0.3
E. Canadian (Acid)	--	0.4	0.9	1.1	1.3	1.5	1.7	2.0
Mexican Frasch	0.5	0.5	0.5	0.3	0.3	0.3	NIL	NIL
Caribbean	0.2	0.7	1.1	1.5	2.0	2.8	4.0	5.0
"Rotterdam" Demand**	-1.3	-1.8	-1.6	-1.4	-1.8	-3.1	-3.6	-3.9

* Available for export to U.S.

** Net of supply minus demand; negative figure implies net demand

Rotterdam is not the only potential market for U.S. exports. However, it is the most favorable market because of established terminals and transportation linkages. Thus, it is the market that establishes the F.O.B. price of U.S. sulfur exports. Under the "free trade" assumptions of the Model, the export and domestic prices of U.S. Frasch sulfur are the same. Thus, the quantity and price of U.S. exports to Rotterdam affect the values of abatement S calculated for different regions within the U.S.

APPENDIX 5

SULFUR DEMAND FORECAST

A.5.1 Fertilizer Sulfur Demand

Fertilizers account for about half of the world demand for sulfur. Most of the sulfur is used in the form of sulfuric acid to solubilize phosphate rock. However, fertilizer S also includes ammonium sulfate (AS) and some direct use of elemental S as a nutrient. The demand for AS is declining because it is a low analysis fertilizer (in terms of nitrogen content) and, hence, is costly to transport and apply when compared with urea or anhydrous ammonia.

In the future the demand for directly applied nutrient S will increase, mostly as elemental S but also as gypsum (e.g., in California where it serves as a soil conditioner). However, on a percentage basis, the growth of S demand is expected to be concentrated in the manufacture of phosphate fertilizers, particularly those of high analysis such as diammonium phosphate (DAP) and triple superphosphate (TSP) rather than normal (or single) superphosphate (NSP). It is also possible that potassium polyphosphates will be commercialized on a large scale. Such products possess the advantage of high analysis by containing both "K_2O" and "P_2O_5".

Some of the more important factors that are expected to affect the future demand for fertilizers and, hence, the imputed demand for fertilizer sulfur are:

(1) New grain varieties ... which were introduced during the past decade and have permitted many developing countries to become self-sufficient in grain production.

(2) First significant usage of fertilizers in many countries ... Older grain varieties (rice, corn, wheat) were not very responsive to fertilizers, while the new varieties are. In consequence, fertilizers were used for the first time in many developing countries during the past decade.

(3) Yield response curve ... For every crop, larger increments in crop yield per unit of fertilization are obtained at low fertilization levels than at high fertilization levels.

(4) Overall trend to higher yield per unit of fertilization ... When items (1) - (3) are considered together, it means that a relative shift in grain production from developed countries (which use high fertilization levels) to developing countries (which use low fertilization levels) will reduce the average quantity of fertilizer needed per unit of grain production.

(5) Meat consumption affects fertilizer demand because several calories of animal feed are required to produce one calorie of human food in the form of meat or dairy products. Fertilizer is used to produce feed grains and, often, on pastures to improve grazing.

(6) Diets have caloric sufficiency in developed countries, i.e. there is little tendency to consume more calories of food per capita. On the other hand, greater meat consumption per capita is associated with rising per capita income. Thus, the latter induces higher fertilizer consumption. Nevertheless, there appears to be a maximum even for consumption of animal products per capita that has already been reached in Oceania and is expected to be reached in the U.S. by 1980. When this occurs, further growth in total caloric demand (including that required to support animal agriculture) will become proportional to population increase.

(7) Exports of grains and animal products increase the apparent per capita consumption of fertilizers in some countries. This is particularly evident in Oceania, but also applies to the U. S. However, Oceania is primarily an exporter of animal products, while the U. S. is primarily an exporter of grains and has been affected by greater self-sufficiency of grain production in developing countries.

(8) Diets are calorically insufficient in many developing countries, but are insufficient in protein also. In consequence, higher income per capita will permit both greater caloric intake and more calories in the form of animal products (India is an exception because of religious prohibitions of meat consumption, etc.). Developing countries, in general, can not earn sufficient foreign exchange to permit large scale importation of food. Hence, expanded food consumption depends on, and is coming from, expansion of domestic food production. This explains the rapid growth of fertilizer consumption in developing countries. Nevertheless, this consumption is still at a low absolute level.

(9) New technology has demonstrated that proteins can be synthesized from hydrocarbons and also that vegetable proteins (e.g. from soybeans) can be spun into products having the same appearance, texture and flavor as various kinds of meat. Consumption of "synthetic meat" is not yet at a significant commercial level. However, both synthetic protein and synthetic meat are expected to become important before the turn of the century. Both of these developments will tend to reduce the demand for fertilizer sulfur and fertilizers in general.

(10) Plantation crops such as cotton, coffee and sugar account for a significant amount of current fertilizer demand in the developing countries. In aggregate, growth in demand for such crops is expected to be slow. Statistically, this will hold down future fertilizer growth rates in the developing countries.

The above factors were taken into account when making the projections of imputed fertilizer S demand recorded in Table 1. It is stressed that these estimates are for sulfur demand not for conventional fertilizer nutrients (N, P_2O_5, K_2O). The projected growth rates for the latter are somewhat higher than for sulfur demand, for example:

Average Compound Growth Rate, 1970-2000, % per year

	N	$N + P_2O_5 + K_2O$	S
Free World	4.5	4.0	3.6

Although it is convenient to express growth on an average compound annual basis, it is expected that actual growth rates will decline progressively, as indicated in the table.

The population forecasts associated with the fertilizer projections are given in Table 2. It will be seen that Oceania is treated as a separate region because of its important role in world agriculture, because of extremely high fertilization with P_2O_5 in Australia, and because of high living standards in Oceania relative to the rest of Asia/Pacific area excluding Japan. Projections of acreage under cultivation and of acres cultivated per capita are given in Tables 3 and 4.

For convenience in making additional calculations, the imputed fertilizer S demand is converted to billions of pounds in Table 5. This makes it possible to calculate the imputed fertilizer S demand in lbs/acre (Table 6), in lbs/capita (Table 7), and in terms of pounds per $1000 of GNP for both the "most probable" and "low economic growth" cases (Tables 8 and 9).

Table 10 shows how the geographical distribution of fertilizer sulfur demand is expected to change during the next fifty years. Last year, 84% of this demand was in developed countries; more than one third was in the U. S. alone. However, by the year 2020, a more even distribution is expected. The same point is evident from Table 7 where fertilizer S demand is expressed on a per capita basis.

Fertilizer sulfur per capita demand is expected to increase more than four-fold in the developing countries during the next fifty years, rising from one twentieth of the average U.S. level now to one seventh of this level by the year 2020. Free world consumption of fertilizer sulfur per capita is expected to double during the same period.

As mentioned above, future fertilizer demand for sulfur is associated primarily with the manufacture of phosphatic fertilizers since the demand for (by-product) ammonium sulfate, a low analysis fertilizer, is declining. However, the geographical location of the sulfur demand, as indicated in Table 1, may be misleading in that large volumes of phosphate fertilizers will be manufactured in countries with major phosphate deposits (e.g. U. S., Spain/Spanish Sahara, Algeria, Morocco, Tunisia). These countries will export both phosphate rock and phosphate fertilizers. In consequence, some of the demand for sulfur attributed to the developing countries (e.g. in Asia) will actually occur in the U. S. and W. Europe where TSP and DAP will be manufactured. This will not affect the worldwide demand for fertilizer sulfur except to the extent that it may be constrained by foreign exchange availability, i.e. by the need for most developing countries to use foreign exchange to pay for imports of P fertilizers or P rock plus sulfur. The parallel need to import potash is another factor that may serve as a brake on fertilizer consumption in developing countries. On the other hand, the latter will move up the fertilizer-response/crop yield curve (increasing quantity of fertilizer required for a unit of crop yield as intensity of fertilization increases as discussed in items 3 and 4), and this will tend to force the use of heavier fertilization.

Last year, on an acreage basis, developing countries used about one ninth as much fertilizer sulfur as developed countries. Fifty years hence, the former are expected to be using one third as much per acre as the developed countries will then be using, or about as much per acre as the developed countries used last year.

It is considered that average fertilization rates in developing countries will not match those in developed countries until rates of population increase decline sharply. The latter is a key to more rapid growth in per capita income and to making it possible to finance the inputs required for modern agriculture. Probably the greatest need is capital for industrial development in order to provide jobs for those displaced from the land by agricultural mechanization. Thus, rapid growth in fertilizer sulfur demand per capita is associated with slow population growth. Clearly, these two factors will have opposite effects on total sulfur demand. On balance, however, a slowing of population growth in developing countries (to a greater degree than projected in Table 2) would be expected to increase fertilizer sulfur demand.

Some water pollution problems, e.g. rain-induced run off of nitrates into rivers, have been experienced in the U. S. Better fertilizer schedules and improvements in weather forecasting may relieve the problem. Nevertheless, it is an indication that maximum feasible rates are being approached in some places. Although the problem has been with N-fertilizers, the impact is on all nutrients since crops require balanced fertilization.

Overall, it is projected that total fertilizer and fertilizer sulfur demand will increase about 5-fold during the next fifty years. On an absolute basis more than half of this increase will be in the developing countries although supplied, to some extent, by exports from the developed countries. However, the rates at which demand grows are expected to decline progressively, and the fertilizer industry will lose its growth label long before the turn of the century. By that time, synthetics of various kinds, including meat-substitute products, are expected to have a restraining influence on fertilizer growth.

A.5.2 Industrial Sulfur Demand

The projections of industrial demand, already presented in the regional supply/demand balance tables in Appendix 4, were based on correlation with constant dollar GNP as discussed in Appendix 1.

On a historical basis, using GNP aggregates for both the "Free World ex U.S." and the Communist Bloc, the following relationship was found between industrial S consumption and GNP in 1958 constant dollars:

	Lbs of S per $1000 of GNP	
Year	Free World ex U.S.	Communist Bloc
1950	19.4	--
1955	20.6	12.5
1960	21.2	16.3
1965	20.8	19.0
1970E	19.5	20.7

The apparent divergence of the trends in these ratios is attributed to a relatively higher, and more advanced, state of industrialization in the Free World countries such that a declining percentage of goods and services (components of GNP) is associated with the forms of industrial production that utilize sulfur and sulfuric acid. Such a decline has been observed in the U.S., and is evident in other Free World countries during the past decade. The estimated value for 1970 is somewhat below the trend line because a recession, in terms of slower growth of industrial production, was experienced in many of the Free World countries. Thus, the downtrend in ratio is expected to continue but not at the apparent decline rate between 1965 and 1970. In fact, the 1975 ratio for the "F.W. ex U.S." is projected to be 19.4 lbs of industrial S per $1000 of GNP. With further moves towards "services economies" in industrialized countries, the ratio is projected to decline as follows:

Year	1975	1980	1985	1990	2000	2010	2020
Ratio	19.4	19.2	18.9	18.5	17.7	17.0	16.3

On the other hand, in 1955, the Communist countries were still at an early stage of (industrial) recovery from World War II. Subsequently, rapid recovery and development occurred in the U.S.S.R. and most E. European countries. In consequence, the level of basic industrial production has risen sharply. The importance of sulfuric acid production to such basic development is clear. Recently, there have been signs of shifts in the economies of the developed Communist countries in the direction of more consumer goods. Thus, while "service economies" are hardly in evidence, the same shifts that occurred in composition of GNP in the Free World countries during the 1960's now appear to be under way in the industrialized parts of the Communist Bloc. Hence, the S/GNP ratio is not expected to rise much further. The following is projected:

Year	1975	1980	1985	1990	2000	2010	2020
Ratio	20.7	19.9	19.4	19.0	18.2	17.4	16.7

In essence, what is being projected is that industrial demand for sulfur is a function of GNP/capita and also of total GNP. Low GNP/capita is consistent with a low level of industrialization. However, certain countries (e.g. Brazil) have highly industrialized areas even though the average level of industrialization is low. Such countries will have a higher level of industrial S demand than would be calculated on the basis of GNP/capita.

As GNP/capita rises so will the demand for industrial sulfur, particularly in the form of sulfuric acid. However, at some point, the contribution of industrial production to GNP will begin to decline on a percentage basis. When this happens, the industrial S/GNP ratio will decline.

It will be appreciated that the above is a hypothesis. While it fits the historical facts, there is a danger that the correlation will become less and less accurate as a quantitative predictor. Thus, it must be pointed out that the projections of industrial sulfur demand beyond the year 2000 are extremely sensitive to the S/GNP ratios that have been projected. Because these ratios have been projected to decline, it means that industrial S demand is projected to grow at a slower rate than GNP. A sharp drop in the ratio would not be expected because some of the "developing countries" will indeed develop industrially. The S/GNP ratio may be expected to increase in such countries thereby partially offsetting the anticipated decline in those that are at a more mature state of development.

Sulfur demand will have been underestimated if the "developing countries" industrialize more rapidly than has been projected (in terms of GNP and GNP/capita). However, in these circumstances the greater economic activity would be accompanied by a greater demand for fossil fuels with a consequent level of sulfur recovery higher than has been projected. Thus, the higher level of S demand would be offset, at least in part, by a higher level of supply, and with a reasonable chance that the net balance would not be affected significantly (i.e. not to the point that world balance would be changed sufficiently to affect the value of abatement S in the U.S.).

A.5.3 Regionalized U.S. Demand

The separate totals of U.S. demand for fertilizer and industrial sulfur, obtained as described in the preceding sections, are shown on a regionalized or disaggregated basis in Tables 11 and 12.

The regionalization was performed by superimposing the simulation of anticipated specific developments, e.g., greatly expanded utilization of the natural resources of the Western states, on a demand pattern prorated from the breakdown of regional demand estimated for 1970.

Development of the coal, shale, phosphate and other mineral resources of the Western states, including copper (oxide as well as sulfide) ores and the various materials recoverable from Great Salt Lake and other brines, will affect both the supply of and demand for sulfur. Part of the demand will be in the form of specific captive uses, e.g., the use of by-product smelter acid to leach oxide ores and low copper content residues separated during the beneficiation of sulfide ores to be treated by pyrometallurgical processes. In some cases, by-product smelter acid may be used for leaching uranium ores. However, it is also anticipated that parts of the Western states will become progressively industrialized as a consequence or multiplier effect of resource development. For example, the construction of coal-to-gas or coal-to-oil plants and the production of shale oil would be expected to be followed by chemical operations based on utilization of various feedstocks and by-products obtained from the new forms of fossil fuel industry (i.e., the conversion plants). Thus, in the long term, the demand for both industrial and fertilizer sulfur is expected to grow significantly in the sulfur Model's "Tucson region," i.e., the Mountain states.

The sum of regionalized fertilizer and industrial demand for sulfur is recorded in Table 13. Because of large quantitative differences in demand among the various regions, the calculations were made to two decimal places (i.e., rounded to the nearest 10,000 LT of annual demand). However, the estimates themselves certainly do not have this accuracy. The lower half of Table 13 illustrates what has been projected when the sulfur demand of the various regions is expressed as a percentage of total U.S. demand.

On an absolute basis, sulfur demand is expected to expand in all regions. However, on a relative basis, demand in the East and South is projected to decline as the West Coast, Mountain states and parts of the Midwest show relative gains:

Regions	% of U.S. Demand for Sulfur in All Forms 1970	2000
Boston, Newark, Norfolk	20.5	16.1
Tampa, New Orleans	42.7	36.1
Chicago, Memphis, Omaha	21.5	24.1
Tucson	7.6	13.9
Seattle, Los Angeles	7.7	9.8

The projected pattern reflects the combined impact of population shifts, resource availability and, in the Chicago region, access to water-borne transportation for movement of both raw materials and products. It is reasoned, further, that the population shift to the West Coast can not be sustained in the long run without the development of "Pacific industries." In concept, the latter would not only be more or less self-sufficient on a domestic basis but would also engage in international trade with Pacific nations such as Japan, China, Australia, countries on the west coast of Latin America, and other countries of S.E. Asia that are expected to undergo considerable agricultural and industrial development during the next fifty years.

The concept of Pacific development is based on analogy with what has occurred during the last century in the mutual economic development of the Eastern U.S. and Western Europe. The latter is expected to continue, but economic growth rates in major Pacific countries are expected to be higher. In this context, the West Coast states may be considered as a "country." The same reasoning would apply to Siberia which, in terms of logistics and international trade is a Pacific country whereas Russia (in its historical sense) and Eastern European countries are oriented towards W. Europe, the Mediterranean and the Middle East.

On a very approximate basis, and recognizing that lines of constant longitude are not involved, it is possible to redefine the Eastern and Western Hemispheres from a logistical standpoint. One of the dividing lines would run through the Canadian Prairies, the U.S. Mountain states, Mexico and Central America, while the Andes would form the natural division in South America. The other dividing line would separate Western Russia from the Siberian republics, and would pass through the Persian Gulf. The countries of East Africa might be considered to be in the Pacific/Indian Ocean "hemisphere," while West and North African countries would be in the Atlantic/Mediterranean "hemisphere." Although extremely crude, this concept is believed to have some merit in relation to future trade patterns in international commodities including sulfur.

APPENDIX 5

TABLE 1

PROJECTIONS OF IMPUTED FERTILIZER SULFUR DEMAND IN MILLION LONG TONS AND COMPOUND ANNUAL GROWTH RATES BY DECADE

	Million Long Tons						Compound Growth, % Per Year				
	1970	1980	1990	2000	2010	2020	70/80	80/90	90/00	00/10	10/20
U.S.	5.03	7.05	9.11	11.01	12.84	14.52	3.4	2.6	1.9	1.55	1.25
Canada	0.47	0.85	1.27	1.73	2.24	2.80	6.1	4.1	3.1	2.6	2.25
Japan	1.12	1.57	1.71	1.85	1.96	2.07	3.4	0.9	0.8	0.6	0.6
European OECD	4.86	5.86	7.11	8.55	10.21	12.03	1.9	2.0	1.9	1.8	1.7
OECD	11.48	15.33	19.20	23.14	27.25	31.42	2.9	2.3	1.9	1.7	1.45
Oceania	0.78	1.34	2.01	2.73	3.56	4.51	5.6	4.1	3.1	2.7	2.4
Devt. F.W.	12.26	16.67	21.21	25.87	30.81	35.93	3.15	2.45	2.0	1.8	1.55
Dev. Asia	0.96	3.14	5.54	8.44	11.80	15.30	12.6	5.85	4.3	3.4	2.7
Africa	0.69	1.07	1.48	2.03	2.62	3.22	4.5	3.3	3.2	2.6	2.1
Latin America	0.63	1.76	3.34	5.43	7.75	10.36	6.0	6.6	5.0	3.6	2.9
Dev. F.W.	2.28	5.97	10.36	15.90	22.17	28.88	10.1	5.7	4.4	3.4	2.7
Free World	14.54	22.6	31.6	41.8	53.0	64.8	4.5	3.4	2.85	2.4	2.1
Communist Bloc	4.0	8.2	12.2	16.7	21.6	27.0	7.3	4.1	3.1	2.65	2.2
World	18.6	30.8	43.8	58.5	74.6	91.8	5.2	3.6	2.9	2.5	2.1
Comm. Bloc as % of World	21.7	26.5	28.0	28.5	29.0	29.4					

APPENDIX 5

TABLE 2

POPULATION PROJECTIONS CORRESPONDING TO FERTILIZER FORECAST

	1970	1980	1990	2000	2010	2020	Ratio 2020/1970
U.S.	205.4	229.1	255.6	282.3	308.8	334.4	1.63
Canada	21.5	26.0	31.1	36.8	42.7	49.1	2.28
Japan	103.4	114.2	126.1	137.9	149.3	160.1	1.55
European OECD	370.1	600.8	434.0	465.3	494.0	519.2	1.40
OECD	700.4	770.1	846.8	922.3	994.8	1062.8	1.52
Oceania	15.4	18.7	22.5	27.0	32.1	38.0	2.47
Devt. F.W.	715.8	788.8	869.3	949.3	1026.9	1100.8	1.54
Dev. Asia	1104.8	1415	1778	2192	2648	3076	2.78
Africa	355.5	455	571	703	857	995	2.80
Latin America	282.6	376	496	634	781	924	3.27
Dev. F.W.	1742.9	2246	2845	3530	4286	4995	2.87
Free World	2459	3035	37.5	4479	5313	6096	2.48
Communist Bloc	1156	1321	1495	1682	1874	2068	1.79
World	3615	4356	5210	6161	7187	8164	2.26

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TABLE 3

PROJECTIONS OF ACREAGE UNDER CULTIVATION

	Million Acres						Ratio
	1970	1980	1990	2000	2010	2020	2020/1970
U.S.	445	432	420	408	395	383	0.86
Canada	104	109	116	124	131	138	1.33
Japan	15	14.6	14.3	14.1	13.8	13.6	0.91
European OECD	301	297	292	289	287	285	0.95
OECD	865	852	843	835	828	820	0.95
Oceania	84	89	94	99	106	114	1.36
Devt. F.W.	949	941	937	934	934	934	0.98
Dev. Asia	852	914	951	971	981	981	1.15
Africa	395	435	482	531	645	786	1.99
Latin America	259	366	467	558	635	702	2.71
	1507	1715	1900	2061	2261	2469	1.64
Free World	2456	2656	2837	2995	3195	3403	1.39
Communist Bloc	1033	1045	1055	1067	1077	1090	1.06
World	3489	3701	3892	4062	4272	4493	1.29

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TABLE 4

PROJECTION OF CULTIVATED ACRES PER CAPITA

	1970	1980	1990	2000	2010	2020	Ratio 2020/1970
U.S.	2.17	1.89	1.64	1.45	1.28	1.15	0.53
Canada	4.84	4.19	3.73	3.37	3.07	2.81	0.58
Japan	0.15	0.13	0.11	0.10	0.09	0.08	0.59
European OECD	0.81	0.74	0.67	0.62	0.58	0.55	0.68
OECD	1.24	1.11	1.00	0.91	0.83	0.77	0.62
Oceania	5.45	4.76	4.18	3.67	3.30	3.00	0.55
Devt. F.W.	1.33	1.19	1.08	0.98	0.91	0.85	0.64
Dev. Asia	0.77	0.65	0.53	0.44	0.37	0.32	0.41
Africa	1.11	0.96	0.84	0.76	0.75	0.79	0.71
Latin America	0.92	0.97	0.94	0.88	0.81	0.76	0.83
Dev. F.W.	0.86	0.76	0.67	0.58	0.53	0.49	0.57
Free World	1.00	0.88	0.76	0.67	0.60	0.56	0.56
Communist Bloc	0.89	0.79	0.71	0.63	0.57	0.53	0.60
World	0.97	0.85	0.75	0.66	0.59	0.55	0.57

Note: Above projections do not take account of double and triple cropping.

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TABLE 5

PROJECTIONS OF IMPUTED FERTILIZER SULFUR DEMAND

(Billion Pounds)

	1970	1980	1990	2000	2010	2020
U.S.	11.27	15.79	20.41	24.66	28.76	32.52
Canada	1.05	1.90	3.04	3.87	5.02	6.27
Japan	2.51	3.52	3.23	4.14	4.39	4.64
European OECD	10.89	13.13	15.93	19.15	22.87	26.95
OECD	25.72	34.34	43.01	51.83	61.04	70.38
Oceania	1.75	3.00	4.50	6.11	7.97	10.10
Devt. F.W.	27.46	37.34	47.51	57.95	69.01	80.48
Dev. Asia	2.15	7.03	12.41	18.91	26.43	34.27
Africa	1.55	2.40	3.32	4.55	5.87	7.21
Latin America	1.41	3.94	7.48	12.16	17.36	23.21
Dev. F.W.	5.11	13.37	23.21	35.62	49.66	64.69
Free World	32.6	50.7	70.7	93.6	118.7	145.2
F.W. ex. U.S.	21.3	34.9	50.3	68.9	89.9	112.7
Communist Bloc	9.0	18.3	27.4	37.3	48.5	60.5
World	41.6	69.0	98.1	130.9	167.2	205.7

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TABLE 6

PROJECTIONS OF IMPUTED FERTILIZER SULFUR DEMAND IN LBS. PER ACRE

	1970	1980	1990	2000	2010	2020	Ratio 2020/1970
U.S.	25.3	36.6	48.6	60.4	72.8	84.9	3.36
Canada	10.1	17.4	24.5	31.2	38.3	45.4	4.50
Japan	167	241	268	294	318	341	2.04
European OECD	36.2	44.2	54.6	66.3	79.7	94.6	2.61
OECD	29.7	40.3	51.0	62.1	73.7	85.8	2.89
Oceania	20.8	33.7	47.9	61.7	75.2	88.6	4.26
Devt. F.W.	28.9	39.7	50.7	62.0	73.9	86.2	2.98
Dev. Asia	2.52	7.69	13.1	19.5	26.9	34.9	13.9
Africa	3.92	5.52	6.9	8.6	9.1	9.2	2.35
Latin America	5.44	10.8	16.0	21.8	27.3	33.1	6.1
Dev. F.W.	3.39	7.8	12.2	17.3	22.0	26.2	7.7
Free World	13.3	19.1	24.9	31.2	37.1	42.7	3.22
Communist Bloc	8.8	17.5	26.0	35.0	45.0	55.5	6.3
World	11.9	18.6	25.2	32.2	39.1	45.8	3.8

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TABLE 7

PROJECTIONS OF IMPUTED FERTILIZER SULFUR DEMAND PER CAPITA (LBS.)

	1970	1980	1990	2000	2010	2020	Ratio 2020/1970
U.S.	54.9	68.9	79.9	87.4	93.1	97.2	1.77
Canada	48.8	73.1	91.3	105.2	117.6	127.7	2.62
Japan	243	308	304	300	294	290	1.19
European OECD	29.4	32.8	32.8	41.2	46.3	51.9	1.77
OECD	36.7	44.6	50.8	56.2	61.3	66.2	1.80
Oceania	114	160	200	226	248	266	2.34
Devt. F.W.	38.4	47.3	54.7	61.0	69.4	75.7	1.97
Dev. Asia	1.95	4.97	6.98	8.63	9.98	11.14	5.7
Africa	4.36	5.27	5.81	6.47	6.85	7.25	1.66
Latin America	4.99	10.5	15.1	19.2	22.2	25.1	5.0
Dev. F.W.	2.93	5.95	8.15	10.1	11.6	13.0	4.4
Free World	13.2	16.7	19.0	20.9	22.2	23.8	1.80
Communist Bloc	7.8	13.9	18.3	22.2	25.9	29.3	3.08
World	11.5	15.8	18.8	21.2	23.3	25.2	2.10

Note that food imports, e.g. by Japan and European OECD, will decrease the effective fertilizer sulfur demand in their areas and increase it in the food exporting areas such as the U.S., Canada and Oceania.

APPENDIX 5

TABLE 8

LBS. OF IMPUTED FERTILIZER SULFUR DEMAND PER $1000 OF GNP IN 1958 CONSTANT DOLLARS

	1955	1965	1970	1980	1990	2000	2010	2020
U.S.	10.4	12.2	15.6	14.7	12.9	10.8	8.9	7.3
Canada	12.0	17.6	17.9	20.2	19.1	16.7	14.1	11.7
Japan	68	27.9	17.2	10.6	6.1	4.1	3.0	2.3
European OECD	21.4	18.5	19.9	15.8	12.6	10.3	8.4	6.9
OECD	16.3	15.8	17.4	14.7	11.9	9.6	7.9	6.4
Far East (ex. Japan)	16.1	18.9	22.0	32.4	31.7	27.9	22.7	18.1
Africa	12.2	20.3	27.2	25.8	22.1	19.3	16.0	13.2
Latin America	1.4	6.1	13.4	21.6	24.2	23.3	20.3	17.1
Non-OECD	9.8	14.9	20.2	28.0	27.9	25.2	21.1	17.2
Free World	15.2	15.7	18.0	17.4	15.3	13.3	11.3	9.5
F.W. ex. U.S.	19.6	18.2	19.5	19.0	16.6	14.5	12.4	10.4
Communist Bloc	14.1	16.0	16.4	20.9	20.0	17.3	14.6	12.0
World	14.9	15.8	17.6	18.2	16.4	14.2	12.1	10.1

APPENDIX 5

TABLE 9

POUNDS OF IMPUTED FERTILIZER SULFUR DEMAND PER $1000 OF GNP IN 1958 CONSTANT DOLLARS - LOW ECONOMIC GROWTH CASE

	1955	1965	1970	1980	1990	2000	2010	2020
U.S.	10.4	12.2	15.6	15.1	14.1	12.7	11.2	9.8
Canada	12.0	17.6	17.9	20.7	20.9	19.6	18.1	16.1
Japan	68	27.9	17.2	11.6	7.4	5.7	4.4	3.6
European OECD	21.4	18.5	19.9	16.2	13.5	11.8	10.6	9.7
OECD	16.3	15.8	17.4	15.3	13.1	11.5	10.2	9.0
Far East (ex. Japan)	16.1	18.9	22.0	34.3	37.0	36.2	33.7	30.6
Africa	12.2	20.3	27.2	26.1	23.1	21.1	18.3	15.9
Latin America	1.4	6.1	13.4	21.9	25.3	26.4	25.2	23.2
Non-OECD	9.8	14.9	20.2	29.0	30.9	30.5	28.3	25.8
Free World	15.2	15.7	18.0	18.0	16.9	16.0	14.8	13.6
F.W. ex. U.S.	19.6	18.2	19.7	19.7	18.4	17.6	16.5	15.3
Communist Bloc	14.1	16.0	16.4	21.3	21.4	20.3	19.2	18.0
World	14.9	15.8	17.6	18.8	18.0	17.0	15.8	14.6

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TABLE 10

PROJECTED DISTRIBUTION OF FREE WORLD FERTILIZER SULFUR DEMAND

(% Basis)

	1970	1975	1980	1985	1990	2000	2010	2020
U. S.	34.6	33.2	31.1	30.1	28.8	26.3	24.2	22.3
Developed Countries excl. U. S.	49.8	46.3	42.5	40.3	38.3	35.5	33.8	32.8
Developed Countries	84.4	79.5	73.6	70.4	67.1	61.8	58.0	58.1
Developing Countries	15.6	20.5	26.4	29.6	32.9	38.2	42.0	44.9
Free World	100	100	100	100	100	100	100	100

APPENDIX 5

TABLE 11

REGIONALIZED PROJECTIONS OF U.S. FERTILIZER S DEMAND

(Million LT of S Equivalent)

Region	1970	1975	1980	1985	1990	2000	2010	2020
Boston	0.02	0.02	0.01	--	--	--	--	--
Newark	0.15	0.16	0.08	0.05	0.05	0.05	0.05	0.05
Norfolk	0.58	0.55	0.46	0.48	0.55	0.66	0.77	0.87
Chicago	0.32	0.36	0.50	0.64	0.76	0.98	1.21	1.44
Memphis	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Omaha	0.09	0.13	0.15	0.19	0.24	0.30	0.38	0.46
Seattle	--	--	--	--	--	--	--	--
Los Angeles	0.18	0.22	0.25	0.29	0.35	0.46	0.58	0.66
Tampa	2.10	2.54	3.19	3.54	3.80	4.20	4.48	4.69
Tucson	0.25	0.38	0.56	0.79	1.18	1.97	2.83	3.68
New Orleans	1.16	1.57	1.82	2.00	2.15	2.36	2.51	2.64
Continental U.S.	4.90	5.97	7.05	8.01	9.11	11.01	12.84	14.52

APPENDIX 5

TABLE 12

REGIONALIZED PROJECTIONS OF U.S. INDUSTRIAL S DEMAND

(Million LT of S Equivalent)

Region	1970	1975	1980	1985	1990	2000	2010	2020
Boston	0.05	0.06	0.07	0.08	0.10	0.14	0.18	0.25
Newark	0.75	0.86	1.01	1.20	1.42	1.96	2.65	3.54
Norfolk	0.42	0.49	0.59	0.72	0.87	1.24	1.73	2.37
Chicago	0.76	0.94	1.16	1.43	1.75	2.55	3.68	5.07
Memphis	0.56	0.66	0.76	0.91	1.07	1.51	2.07	2.84
Omaha	0.28	0.34	0.39	0.46	0.54	0.74	1.03	1.37
Seattle	0.25	0.30	0.36	0.44	0.53	0.78	1.11	1.56
Los Angeles	0.31	0.39	0.49	0.62	0.79	1.22	1.85	2.73
Tampa	Negligible (in relation to fertilizer S demand)							
Tucson	0.48	0.58	0.70	0.86	1.05	1.54	2.17	3.01
New Orleans	0.84	0.99	1.18	1.43	1.75	2.54	3.64	5.13
Continental U.S.	4.70	5.61	6.71	8.15	9.87	14.22	20.11	27.87

APPENDIX 5

TABLE 13

REGIONALIZED PROJECTIONS OF TOTAL U.S. DEMAND FOR SULFUR IN ALL FORMS

(Million LT of S Equivalent)

Region	1970	1975	1980	1985	1990	2000	2010	2020
Boston	0.07	0.08	0.08	0.08	0.10	0.14	0.18	0.25
Newark	0.90	1.02	1.09	1.25	1.47	2.01	2.70	3.59
Norfolk	1.00	1.04	1.05	1.20	1.42	1.90	2.50	3.24
Chicago	1.08	1.30	1.66	2.07	2.51	3.53	4.89	6.51
Memphis	0.61	0.70	0.79	0.94	1.10	1.54	2.10	2.87
Omaha	0.37	0.47	0.54	0.64	0.78	1.04	1.41	1.83
Seattle	0.25	0.30	0.36	0.44	0.53	0.78	1.11	1.56
Los Angeles	0.49	0.61	0.74	0.91	1.14	1.68	2.43	3.39
Tampa	2.10	2.54	3.19	3.54	3.80	4.20	4.48	4.69
Tucson	0.73	0.96	1.26	1.65	2.23	3.51	5.00	6.69
New Orleans	2.00	2.56	3.00	3.43	3.90	4.90	6.15	7.77
Continental U.S.	9.60	11.58	13.76	16.16	18.98	25.23	32.95	42.39
• Percentage Basis								
Boston	0.7	0.7	0.6	0.5	0.5	0.6	0.5	0.6
Newark	9.4	8.8	7.9	7.7	7.7	8.0	8.2	8.5
Norfolk	10.4	9.0	7.6	7.4	7.5	7.5	7.6	7.6
Chicago	11.3	11.2	12.1	12.8	13.2	14.0	14.8	15.3
Memphis	6.3	6.0	5.7	5.8	5.8	6.0	6.4	6.8
Omaha	3.9	4.1	3.9	4.0	4.1	4.1	4.3	4.3
Seattle	2.6	2.6	2.6	2.7	2.8	3.1	3.4	3.7
Los Angeles	5.1	5.3	5.4	5.6	6.0	6.7	7.4	8.0
Tampa	21.9	21.9	23.2	22.0	20.1	16.7	13.6	11.1
Tucson	7.6	8.3	9.1	10.2	11.7	13.9	15.2	15.8
New Orleans	20.8	22.1	21.9	21.3	20.6	19.4	18.6	18.3

APPENDIX 6

COST ASSUMPTIONS

A.6.1. Transportation Costs

Transportation costs depend on a number of factors:

- what is being carried
- the form in which it is carried
- the mode of transportation (tanker, freighter, barge, hopper car, tank car, etc.)
- the size of parcel
- loading and/or unloading costs
- distance
- special restrictions, e.g., that shipment must be made in a U.S. flag vessel (Jones Act)
- spot charter, long-term charter or contract of affreightment rates
- special arrangements such as unit trains or backhaul provisions

Sulfur is transported either as a bulk, powdered solid or as a (heated) liquid. U.S. deliveries are made by tankers or barges to more than two dozen liquid terminals. The latter are located on the Gulf Coast, at Tampa, on the E. Coast, and on the Mississippi River system. Local delivery from these terminals is made, as liquid, by rail or tank-truck. In addition, there are several customer terminals to which liquid is delivered by U.S. and Mexican Frasch producers. For the most part, Canadian exports to the Mountain and Midwest states are as liquid in rail tank-cars.

Superimposed on the transportation pattern for elemental sulfur is that for sulfuric acid. The latter moves by tank-truck, barge and R.R. tank-car. Because of much higher transportation costs, when considered on an S-value basis*, sulfuric acid is seldom shipped more than 150 miles. Furthermore, acid is normally shipped in approximately 100% concentration even though actual use often involves much lower concentrations, ranging down to 10% and even lower.

The importance of transportation costs varies with the value of the material being transported. Because sulfur has a low unit value (e.g., in $ per LT), transportation costs represent a significant part of the delivered price ranging from as little as 10-15% to as much as 70%.

On a ton-mile basis water-borne transportation costs, particularly for foreign flag vessels, may be only 10%, or even less, of U.S. rail costs. In consequence, there is a greater interconnection of world sulfur markets by sea than there is of U.S. markets by land.

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*i.e. a sulfur equivalent basis.

The Jones Act, which requires shipments between U.S. ports in (high cost) U.S. vessels, produces the seeming anomaly of making it cheaper to ship U.S. Frasch sulfur to N. Europe (in a foreign flag vessel) than to ship it to Boston (in a U.S. flag carrier).

In late 1970, the price of sulfur ex a Rotterdam terminal was about $26/LT. With a $6/LT liquid tanker charge, this price netted back to about $20/LT F.O.B. Gulf Coast. At that time*, the freight for Canadian sulfur between Vancouver and Rotterdam was about $10/LT. After adding a melting charge at the delivery end (Rotterdam) and also the unit train costs from Calgary to Vancouver together with handling and loading charges in Vancouver, the netback to Calgary was about $7/LT. At the same time, the netback to the Mexican export port of Coatzacoalcos was approximately the same as that to U.S. Gulf ports (Galveston, Beaumont, Port Sulphur). Both French and Polish sulfur was also entering N. European markets with transportation costs from Bayonne (France) and Gdansk (Poland) of about $5/LT. The actual price at Rotterdam depended on a number of factors (e.g., whether the sulfur offered is dark or bright, liquid or solid, spot or long-term contract), but the netbacks to major supply points approximated:

	Netback $/LT	Transportation Cost as % of Delivered Price
U.S. Gulf Ports	20	23
Coatzacoalcos	20	23
Vancouver	15	--
Calgary	7	73
Bayonne (France)	21	19(1)
Gdansk (Poland)	21	19(1)

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(1) These percentages do not include the internal transportation costs for delivering French and Polish sulfur to the ports of Bayonne and Gdansk respectively.

The very high marine transportation rates experienced during 1970 have fallen back to normal, or below normal, levels. In consequence, the Vancouver/Rotterdam rate may now be of the order of $6/LT for favorable charters. A comparable reduction has not occurred between Beaumont or Port Sulphur and Rotterdam because the liquid tankers used for the shipments are owned by Sulexco.

The North European price situation connects back into U.S. pricing through the netbacks to principal supply points in N. America. Theoretically, $7/LT F.O.B. Alberta sulfur could move across the border into Montana and be delivered there for little more than $10/LT. Clearly, it would not be possible for U.S. Frasch producers to come close to meeting such a price. Even if the Alberta F.O.R. price were to be $15/LT, it would still have a competitive edge** in large areas within the Mountain and Midwest states that cannot be supplied directly by barge up the Mississippi River system. Many points on this system can be reached by barge from U.S. Gulf locations for less than $4/LT. Using a notional "free on barge" price of $20/LT,* it would appear that U.S. Frasch sulfur could be delivered to terminals on the Mississippi River system for $24/LT or less. To meet this competition, starting with an F.O.R. Alberta price of $7/LT, would mean that W. Canadian sulfur could not afford a transportation cost of more than $17/LT. This, in fact, is the approximate cost of shipment from Calgary to Chicago.

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* When marine spot charter rates were abnormally high.

** Except over local supplies recovered from sour natural gas, etc.

The above discussion summarizes several of the most important transportation cost factors that have affected sulfur markets recently. However, this is not a sufficient basis for projecting future transportation cost relationships. A major problem is that rail costs have been increasing faster than costs of other forms of transportation. A partial way around this difficulty has been the arrangement of deliveries by "unit train." The technique was first used for shipment of coal (which has an even lower unit value than sulfur), and was devised by the railroads as a response to experimentally demonstrated technology of moving coal by slurry pipeline.** Unit trains move Duval's (Pennzoil United) sulfur from Culbertson county to Galveston, Texas, and also move Canadian sulfur from Alberta to Vancouver. In the future, it seems possible that sulfur will be shipped by unit train*** between Alberta and one or more Midwest points.

The use of unit trains has permitted R.R. costs not much higher than the low rates achievable with barge shipment. Unfortunately, however, rail operating costs are increasing faster than barge costs. Hence, when the unit train contracts are renegotiated it seems certain that the rates will be hiked. Consequently, the approximate parity that has existed between unit train and barge rates will not be maintained.

A principal reason that unit trains have been able to lower costs relative to conventional shipments by rail is the generally poor utilization of rolling stock. Prompted by difficulties in effecting deliveries of coal during 1970 due to limited availability of hopper cars, demurrage rates were increased. It remains to be seen whether this will significantly improve utilization of rolling stock for transportation purposes (as opposed to customers' use of hopper cars for storing coal). In some cases, unit trains get around this difficulty by requiring the cars to be owned by the company making the shipments rather than by the railroad. Obviously, this provides the customer with the incentive for using the transportation equipment for its intended purpose and for arranging alternative ways of storing the material shipped.

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* Somewhat lower at the Frasch mine.

** The technique has been revived for application to Peabody's (Kennecott) Black Mesa project.

*** The introduction of unit trains has had the effect of lowering the statistical average of rail costs while, at the same time, the costs of individual modes of rail shipment have been increasing rapidly.

A combination of railroad consolidation with use of computer programs to keep track of rolling stock may eventually bring the escalation of rail shipment costs under control. However, there is no immediate prospect of this occurring. In fact, the prospects appear so poor, at least for another decade, that it has been necessary to project increases in rail costs relative to other modes of transportation.* The matter is of critical importance in certain markets, e.g.:

- W. Canadian delivery costs to Chicago are projected to increase relative to deliveries of Frasch S up the Mississippi by barge.
- W. Canadian delivery costs to Rotterdam will decrease relative to Canadian delivery costs to Chicago (in spite of the need to move to Rotterdam by first making a rail shipment from Alberta to Vancouver).
- Duval's cost of shipping S from Culbertson county to Galveston will increase on a relative basis.
- Landlocked locations such as Arizona will be relatively disadvantaged--doubly so if acid has to be shipped (by rail).

These considerations are directly pertinent to the future value of abatement sulfur. However, some additional points must be made:

- Unit trains are feasible only for high volume movements between fixed points.
- Elemental S can be stored until a sufficient quantity is available for economic shipment by barge or bulk-carrier. (This consideration does not apply to unit trains which must be kept in constant operation.)
- Sulfuric acid cannot be stored, except at significant cost and as limited by available storage capacity. This would seem to favor (or even mandate) the establishment of local markets for abatement acid that could be served by owned transport.** A transportation strike of any kind could force the shutdown of abatement acid plant--with serious consequences for an electric utility.

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* The Sulfur Model is constructed on a constant dollar basis, because any other basis introduces extreme complications. Therefore, it was with great reluctance that rail costs were projected to escalate relative to barge or marine transportation rates. However, it was felt that it would be unrealistic to ignore the fact that rail costs have been rising so rapidly, and must continue to rise in this manner until labor and equipment can be employed more effectively.

** Probably road tankers or, in special cases, pipeline to nearby petrochemical plants.

- Little or no value can be projected for abatement S recovered by a poorly located plant. This point has pertinence on a local as well as on a macrogeographical basis. It is rather obvious that sulfur recovery in Arizona is unfavorably located. It may be less obvious that recovery of abatement S from mine-mouth power plants in Eastern states could also be poorly located with respect to marketing of S values.

- In general, recovery of abatement S at plants directly on the Mississippi River system, or with direct access to marine transportation, may be considered as favorable from the standpoint of marketing S values.

- Prices at locations some distance from main terminals will be higher than at the terminals (to take account of local delivery costs). Hence, there may be specific locations where abatement S can enjoy a good netback. This is possible if local industry could absorb *all* of the abatement supply.

- Special situations involving major suppliers may develop. For example, acid recovered from nickel and copper smelting in the Sudbury/Timmins area of Ontario may be shipped to N. Europe *if long range contracts can be arranged*. This possibility arises because of the very large quantity of acid potentially available and the fact that there is outlet for merchant acid in N. Europe. Recovery in the form of sulfuric acid, while having a transportation disadvantage relative to elemental sulfur, has the potential advantage to a consumer of acid of not having to manufacture it. This is why, in the future, and subject to *local* demand limitations, recovered acid may be able to enjoy a higher recovery value than elemental sulfur. This topic is discussed in detail in Part 2 of the report.

The basic data and assumptions for projected 1975 transportation costs are given in Tables 1 and 2. The delivery cost for acid, e.g., from Tucson to Los Angeles, is expressed in terms of "$ per LT of acid." Subsequently, such costs are converted to "$ per LT of S-value in the form of acid" for the purpose of handling acid and elemental S simultaneously in the computer calculations. This is done by multiplying the "$ per LT of acid" delivery cost by 3.06.

For subsequent years, the following escalations of rail transportation costs *relative to* other transportation modes were assumed:

1975 - 1980	2%/yr.,	i.e.	x 1.104
1980 - 1985	1.5%/yr.,	i.e.	x 1.077
1985 - 2000	1%/yr.,	i.e.	1985 - 1990: x 1.051
			1990 - 2000: x 1.1046
2000 - 2010	0.5%/yr.,	i.e.	x 1.051
2010 - 2020	0.5%/yr.,	i.e.	x 1.051

These relative escalations are tantamount to assuming that U.S. railroads will be considerably automated by about 1985. The results of these assumptions, in terms of total delivery cost, are shown in Table 3. The following assumptions are also implicit in the cost projections:

- Unit train link between Calgary and Chicago by 1980.
- Transshipment out of Chicago (unit train) terminal by barge after establishment of Calgary/Chicago unit train link.
- Calgary/Vancouver pipeline assumed by 1990.
- Calgary/Chicago pipeline by 1990, with transshipment out of pipeline terminal by barge.
- Rail movement between Vancouver and Seattle.

For the computer calculations, the relative advantage to the customer of being able to receive acid instead of elemental S is simulated by deducting \$6.85/LT (for 1975 and 1980 cases) and \$27.42/LT (for subsequent years) from the projected total delivered cost of acid. The difference between these two figures reflects the differential advantage of purchasing acid (a) when this would require the shutdown of existing acid manufacturing capacity and (b) instead of building new capacity for manufacturing acid.

A.6.2. Production Costs and F.O.B. Price Basis

The costs of producing Frasch sulfur have been discussed by Manderson.* In the first of the two papers cited, the following estimates are given:

Type of Frasch Production	Production 10^6 LT 1970	1975	Operating Cost	R.O.I.●	S.G.&A.●	Min. F.O.B.●
Low Cost	3.0	3.0	7	3	4	14
Medium Cost	5.2	5.8	11	4	4	19
High Cost	2.8	2.8	15	8	4	27
	11.0	11.6				

● These quantities are in \$/LT.
R.O.I. = Return on Investment (15% before taxes)
S.G.&A. = Severance taxes and general corporate expenses
Min. F.O.B. = Minimum F.O.B. price

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* (1) "The Sulfur Outlook," M. C. Manderson, Chemical Engineering Progress (CEP) technical manual, A.I.Ch.E., 1971.
(2) "World Sulfur Outlook into the Late 1970's," M. C. Manderson, American Chemical Society Annual Convention, September, 1970.

The "minimum F.O.B. prices" are hypothetical because it is clear that this range of prices could not co-exist. However, if these figures are treated as costs, it is possible to calculate a weighted average price for each year based on the "production" cited:

	1970	1975
Weighted average, \$/LT	19.7	19.6
Total production, 10^6 LT	11.0	11.6

The "production" refers more to productive capacity than to actual production which amounted to about 7 million LT in 1970. Under continuing conditions of oversupply, it is hardly likely that much high-cost Frasch production will occur in 1975. If just the low and medium cost production is considered, the weighted average "minimum F.O.B. price" would be \$17.3/LT.

The second paper revises the above numbers somewhat and presents them in a different form. In this case, the different types of production are characterized according to the annual production of individual (hypothetical) mines, together with their associated water rates and fixed investments:

	Annual Production 10^6 LT	Water Rate gals./LT	Fixed Investment 10^6 \$
Low Cost	1.4	1,600	15.5
Medium Cost	0.35	3,000	8.1
High Cost	0.175	5,000	7.4

The above quantities are then used to calculate hypothetical selling prices for the different cost classes of Frasch production (\$/LT):

	Operating Cost	Loading and Severance	General Corp. Exp.	Profit, 15% at on Fixed Invest.	F.O.B. Price
Low Cost	5.0	1.7	0.9	3.3	10.9
Medium Cost	9.5	1.7	1.4	6.9	19.5
High Cost	15.0	1.7	2.0	12.7	31.4

It will be noted that the basis has been shifted from 15% R.O.I. before taxes in the first paper to 15% R.O.I. after taxes in the above tabulation. There is a conceptual difficulty in either of these cases in that it is hardly possible to expect the same R.O.I. on high and low cost production. Presumably, if high cost production can be justified by market conditions or expectations, then the profit on low cost production would be spectacular.

It is of some interest to review the production cost figures before adding any profit margin ($/LT):

	Operating Costs Plus Expenses (Zero R.O.I.)
Low Cost	7.6
Medium Cost	12.6
High Cost	18.7

These figures suggest that "low cost" production would begin to be marginally profitable (i.e., produce a positive cash flow) at about $8/LT, while "medium cost" production would require about $13/LT. These values are less than those obtained by adding "S.G.&A." to the Operating Costs cited in the first paper. This is surprising since operating costs, particularly those for fuel and labor, have been rising.

Information on U.S. Frasch S production costs is also reported by Hazleton.* Cases are worked, using different assumptions, that result in operating costs ranging from $4.81/LT to $22.02/LT. Actual operating costs for Jefferson Lake's Long Point dome** for the year 1961-1963, after deduction of estimated royalty payments, are stated to be:

	Output 1000 LT	Water Rate Gals./LT	Operating Cost $/LT
1961	230	4900	9.82
1962	256	4550	9.11
1963	234	4910	9.96

Adding back the royalty expense, and making an allowance for other expenses, would raise the F.O.B. cost to about $18/LT (without any return on investment). Labor and fuel costs have risen since 1963 so that the F.O.B. cost of sulfur from Long Point may now approximate $20/LT. This figure is somewhat higher than the estimated average netback obtained by the U.S. Frasch industry in 1970/71. Hence, the question arises: "How can Long Point continue in production?" A partial answer is that much of the production is used captively.

In the Sulfur Model "New Orleans" is taken to be representative of actual terminals at Galveston, Beaumont, Port Sulphur and other principal locations where Frasch sulfur is loaded. The "F.O.B. Orleans" prices used in the Model include the cost of moving sulfur from the individual mines to the main terminals and of loading it aboard a vessel, barge, etc. These costs (which could be applied after those considered by Manderson and Hazleton) vary considerably. For example, shipment by unit train from Culbertson county into and out of storage at Galveston may cost about $10/LT. Thus, even though the W. Texas mining operation is said to have favorably low production costs,* the F.O.B. Galveston cost cannot be less than $15/LT. The leading Frasch S producers, Freeport Minerals and Texas Gulf Sulphur, may have the theoretical capability of operating with positive cash flow (from their sulfur business) with an average "F.O.B. Orleans" price below $15/LT. However, it is not considered likely that either company would be willing (or will be forced) to do this. Even though direct operating costs may be reduced per unit of production by shutting down all but the lowest cost domes, other costs would rise if production were to be cut below a certain level. These costs are associated with the operation of owned liquid tankers and terminals, as well as involving marketing and administrative expenses. Furthermore, the Frasch S producers are well aware that labor and fuel costs will continue to rise. As discussed elsewhere, a principal strategy must be to secure and continue to develop the Tampa/Bartow market and to maintain reasonable overall levels of production by capitalizing on marketing strengths in other locations.

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* "The Economics of the Sulphur Industry," Chapter 3, Jared E. Hazleton, RFF, 1970.

** Generally considered to be "medium cost".

The minimum "F.O.B. Orleans" price may be approached in another way. The difference in delivery cost (after correcting for melting charges, terminalling costs, etc.) between Calgary/Tampa and Orleans/Tampa is estimated to be about $12/LT. Hence, with an "F.O.B. Orleans" price of $12/LT the U.S. Frasch producers would be competitive with W. Canadian production even if the latter were to be offered at $NIL/LT. It is obvious that Alberta sulfur will not be given away. Among other things, this would deny royalty revenue** to the Province of Alberta. In addition, some costs are associated with sales in addition to the cost of loading the sulfur "free on rail" (F.O.R.) in Alberta. Consequently, no circumstance can be foreseen in which the F.O.R. Calgary price would fall below about $5/LT.*** The latter is equivalent to a minimum "F.O.B. Orleans" price of $17/LT. Consequently, the Sulfur Model does not consider cases much below this price level in the computer calculations. Nevertheless, the hypothetical effects of lower W. Canadian prices are quite easy to estimate from the cases that have been calculated.

There have been fluctuations in exchange parities between the U.S. and Canadian dollars. A large fluctuation could invalidate the reasoning given above. However, the currencies are now trading essentially at par. Given the high level of reciprocal trade between the U.S. and Canada, it seems likely that approximate parity will continue. However, if the Canadian $ were to go to a substantial premium relative to the U.S. $--15% is as much as can be conceived--Alberta S producers could remain competitive by cutting F.O.R. Calgary prices by $1.50/LT, a remedy that is clearly within their capability. If the exchange rate were to shift in the other direction, a small price increase would maintain the balance.

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* As low as the lowest cost (other) Frasch production.

** Which is based on sales realizations.

*** Current actions by the Alberta Provincial Government may result in prices above $10/LT and, perhaps, as high as $15/LT.

Of possibly greater importance is the potential impact of realignment of foreign exchange rates on export sales of both U.S. and Canadian producers in the Eastern Hemisphere. Both dollars and the Mexican peso are likely to float together against the yen and European currencies. The effect should be to make exports of sulfur from N. America more competitive in foreign markets.

In summary, it is considered that production from the more efficient (i.e., lower cost) U.S. Frasch mines will remain economically viable, that this will entail a lowering of production below recent levels, that some marginal production remains to be shut down, and that there is no likelikhood for many years of reactivation of high cost production. Although Canadian producers could destroy the profitability of the U..S. Frasch industry, this is extremely unlikely to happen because it would also remove profitability from the Canadian industry. At the same time, the Canadian producers hold the initiative and, because of rising by-product production in Alberta, may be expected to keep pressure on foreign export markets.

APPENDIX 6

TABLE 1

TRANSPORTATION AND DELIVERY MODES (1975)

Supply Point	Destination	Via	Mode	Approx. Distance	Discharge
Tucson	Los Angeles	Direct	Rail	500	Pump Out
New Orleans	Boston	Direct	Liquid Tanker	2320	Pump Out
	Newark	Direct	Liquid Tanker	2070	Pump Out
	Norfolk	Direct	Liquid Tanker	1880	Pump Out
	Chicago	Direct	Liquid Barge	1270	Pump Out
	Memphis	Direct	Liquid Barge	550	Pump Out
	Omaha	Direct	Liquid Barge	1370	Pump Out
	Tampa	Direct	Liquid Tanker	520	Pump Out
	Rotterdam	Direct	Liquid Tanker	5540	Pump Out
Coatzcoalcos	Boston	Direct	Liquid Tanker	2440	Pump Out
	Newark	Direct	Liquid Tanker	2190	Pump Out
	Norfolk	Direct	Liquid Tanker	2000	Pump Out
	Tampa	Direct	Liquid Tanker	1130	Pump Out
	Rotterdam	Direct	Liquid Tanker	5810	Pump Out
Aruba	Boston	Direct	Bulk Carrier	2280	Melt, Pump Out
	Newark	Direct	Bulk Carrier	2030	Melt, Pump Out
	Norfolk	Direct	Bulk Carrier	1840	Melt, Pump Out
	Tampa	Direct	Bulk Carrier	1650	Melt, Pump Out
	Rotterdam	Direct	Bulk Carrier	4900	Melt, Pump Out

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NOTE: All Distances in Statute Miles.

TABLE 1 Cont'd

Supply Point	Destination	Via	Mode	Approx. Distance	Discharge
Calgary	Boston	Vancouver	Unit Train, Bulk Carrier	640 + 7180	Melt, Pump Out
	Newark	Vancouver	Unit Train, Bulk Carrier	640 + 6930	Melt, Pump Out
	Norfolk	Vancouver	Unit Train, Bulk Carrier	640 + 6740	Melt, Pump Out
	Chicago	Direct	Rail	1570	Pump Out
	Memphis	Direct	Rail	2160	Pump Out
	Omaha	Direct	Rail	1410	Pump Out
	Seattle	Vancouver	Unit Train, Rail	640 + 120	(3)
	Los Angeles	Vancouver	Unit Train, Bulk Carrier	640 + 1380	Melt, Pump Out
	Tampa	Vancouver	Unit Train, Bulk Carrier	640 + 6140	Melt, Pump Out
	Rotterdam	Vancouver	Unit Train, Bulk Carrier	640 + 10220	Melt, Pump Out
Sudbury	Buffalo (1)	Niagara Falls	Unit Train, Rail	400 + 30	Pump Out
	Detroit (2)	Sarnia	Unit Train, Rail	400 + 70	Pump Out
	Rotterdam	Sorel	Unit Train, Tanker	440 + 3560	Pump Out

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* Unit Train is a future possibility.

1. Part of Boston Region.
2. Part of Chicago Region.
3. Assumed to be melt and pump out for the purpose of cost calculations.

NOTE: All Distances in Statute Miles.

APPENDIX 6

TABLE 2

TRANSPORTATION AND DELIVERY COSTS ($/LT) ESTIMATED FOR 1975

Supply Point	Destination	Transportation Cost (1)	Transportation Cost (2)	Handling Costs	Total Delivery Cost, $/LT	Transportation Mills/Ton Mile
Tucson	Los Angeles	11.25	--	0.25	11.50	22.5
New Orleans	Boston	6.26	--	0.40	6.66	2.7
	Newark	5.59	--	0.40	5.99	2.7
	Norfolk	5.08	--	0.40	5.48	2.7
	Chicago	3.81	--	0.40	4.21	3
	Memphis	1.65	--	0.40	2.05	3
	Omaha	4.11	--	0.40	4.51	3
	Tampa	1.40	--	0.40	1.80	2.7
	Rotterdam	6.00	--	0.40	6.40	1.08
Coatzcoalcos	Boston	2.64	--	0.40	3.04	1.08
	Newark	2.37	--	0.40	2.77	1.08
	Norfolk	2.16	--	0.40	2.56	1.08
	Tampa	1.22	--	0.40	1.62	1.08
	Rotterdam	6.27	--	0.40	6.67	1.08
Aruba	Boston	2.28	--	2.00	4.28	1.0
	Newark	2.03	--	2.00	4.03	1.0
	Norfolk	1.84	--	2.00	3.84	1.0
	Tampa	1.65	--	2.00	3.65	1.0
	Rotterdam	4.90	--	2.00	6.90	1.0

TABLE 2 Cont'd

Supply Point	Destination	Transportation Cost (1)	Transportation Cost (2)	Handling Costs	Total Delivery Cost, $/LT	Transportation Mills/Ton Mile	
Calgary	Boston	5.76	4.31	4.27	14.34	9.0	0.6
	Newark	5.76	4.16	4.27	14.19	9.0	0.6
	Norfolk	5.76	4.04	4.27	14.09	9.0	0.6
	Chicago	17.27	--	0.40	17.67	11	--
	Memphis	23.76	--	0.40	24.16	11	--
	Omaha	15.51	--	0.40	15.91	11	--
	Seattle	5.76	2.16	4.27	12.19	9.0	18
	Los Angeles	5.76	1.38	4.27	11.41	9.0	1.0
	Tampa	5.76	3.68	4.27	13.71	9.0	0.6
	Rotterdam	5.76	6.13	4.27	16.16	9.0	0.6
Sudbury	Buffalo	4.52	0.68	0.50	5.70	11.3	22.5
	Detroit	4.52	1.58	0.05	6.60	11.3	22.5
	Rotterdam	4.97	4.81	2.50*	12.28	11.3	1.35

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* Includes estimate of storage costs in Sorel.

APPENDIX 6

TABLE 3

PROJECTED DELIVERY COSTS, $ PER LT OF S VALUE

Supply Point	Destination	1975	1980	1985	1990	2000	2010	2020
Tucson*	Los Angeles	35.19	38.77	42.01	43.79	48.29	50.70	53.24
New Orleans	Boston	6.66			- No Change -			
	Newark	5.99			- No Change -			
	Norfolk	5.48			- No Change -			
	Chicago	4.21			- No Change -			
	Memphis	2.05			- No Change -			
	Omaha	4.51			- No Change -			
	Tampa	1.80			- No Change -			
	Rotterdam	6.40			- No Change -			
Coatzcoalcos	Boston	3.04			- No Change -			
	Newark	2.77			- No Change -			
	Norfolk	2.56			- No Change -			
	Tampa	1.62			- No Change -			
	Rotterdam	6.67			- No Change -			
Aruba	Boston	4.28			- No Change -			
	Newark	4.03			- No Change -			
	Norfolk	3.84			- No Change -			
	Tampa	3.65			- No Change -			
	Rotterdam	6.90			- No Change -			

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* = 100% Acid

TABLE 3 Cont'd

Supply Point	Destination	1975	1980	1985	1990	2000	2010	2020
Calgary	Boston	14.34	15.26	16.32	14.98		- No Change -	
	Newark	14.19	15.11	16.17	14.83		- No Change -	
	Norfolk	14.09	15.01	16.07	14.73		- No Change -	
	Chicago	17.67	16.73	19.00	16.10		- No Change -	
	Memphis	24.16	20.49	23.16	20.26		- No Change -	
	Omaha	15.91	17.98	20.85	20.83		- No Change -	
	Seattle	12.19	13.45	14.91	14.03	14.36	14.73	15.13
	Los Angeles	11.41	12.33	13.39	12.05		- No Change -	
	Tampa	13.71	14.63	15.69	14.35		- No Change -	
	Rotterdam	16.16	17.08	18.14	16.80		- No Change -	
Sudbury*	Buffalo	17.44	19.03	20.38	21.33	23.41	21.51	25.67
	Detroit	20.20	22.12	23.72	25.46	27.26	28.58	29.96
	Rotterdam	37.58	39.17	40.45	41.37	43.37	44.43	45.53
Chicago	Newark	--	--	--	10.20		- No Change -	
	Norfolk	--	--	--	9.69		- No Change -	
	Memphis	--	--	--	2.16		- No Change -	
	Tampa	--	--	--	6.01		- No Change -	
	Rotterdam	--	--	--	10.61		- No Change -	
Newark	Norfolk	--	--	--	--	--	1.80	1.80
	Rotterdam	--	--	--	--	--	6.90	6.90
Memphis	Tampa	--	--	--	--	--	3.96	3.96
	Rotterdam	--	--	--	--	--	8.45	8.45
San Francisco	Seattle	--	--	--	--	--	5.24	5.24

- - - - - - - - -

* = 100% Acid

APPENDIX 7

COMPUTER MODEL

A.7.1 The LP Program

The computer program used in the Sulfur Supply/Demand/Price Model is a variation of the transportation linear program. In the application to the Sulfur Model the total delivered cost to the sulfur demand regions is minimized.

$$(1) \quad \sum_{i,j} X_{ij} C_{ij} = \text{minimum}$$

where X_{ij} = quantity of sulfur equivalents delivered from supply region i to demand region j

C_{ij} = delivered price of a unit of sulfur equivalent delivered from supply region i to demand region j

The delivered price C_{ij} is the sum of the F.O.B. price at the supply point i, the transportation cost for the transaction link ij, and any other delivery costs incurred.

The minimization specified by equation (1) is subject to the following constraints

$$(2) \quad \sum_{j} X_{i,j} \leq S_i$$

where S_i = available supply at supply region i

$$(3) \quad \sum_{i} X_{i,j} = D_j$$

where D_j = total demand at demand region j.

The demand regions are further divided into sub-regions which can have an upper limit on their receipt of sulfur equilvalent from specified supply regions, k.

$$(3a) \quad \sum_{i=1}^{i=k} X_{i,j} \leq D_j^k$$

where D_j^k is the total demand at region j which can be received from supply regions I=1 to k. This division into sub-demand regions is used for transactions of acid sulfur where the market for sulfur as acid in the demand region can be less than the total demand for sulfur equivalent in the demand region. The supply regions i=1 to k are then specified as acid supply points.

The demand regions are also further divided into sub-regions which can have a lower limit on their receipt of sulfur equivalents from a specified supply region, ℓ.

(3b) $X_{\ell,j} \geq D_j^{\ell}$

where D_j^{ℓ} is the minimum quantity of sulfur equivalent that the model will accept in demand region j from the supply point, ℓ. This type of constraint is used to force a supplier to sell in a particular demand region. This is necessary during the early years of the forecast when a given supplier may have sulfur receiving facilities which enable specific forms of sulfur to be delivered to the demand region and customers can currently accept only that specific form of sulfur (e.g., liquid sulfur). In latter years of the forecast it is used to force multi-source supply in a region.

Each of these demand sub-regions is subject to the overall constraint specified by equation (3).

The linear program output includes:

(1) The calculated quantity of sulfur equivalent, X_{ij}, transferred between supply region i and demand region j subject to the constraints and minimization restriction discussed above. This calculated quantity, X_{ij}, is taken to be the SALES of sulfur equivalent.

(2) Dual variables which are interpreted as follows:

  (a) the incremental cost change to the total problem resulting from an incremental demand of one unit of sulfur equivalent in a specified demand region, j. This variable is taken to be the DELIVERED VALUE of a unit of sulfur equivalent in demand region j.

  (b) the incremental cost change to the total problem resulting from an incremental supply of one unit of sulfur equivalent from a specified supply region, i. This variable is taken to be the marketing PROFIT of a unit of sulfur equivalent from supply region i. When PROFIT is added to the FOB PRICE in the supply region, the supplier NETBACK is obtained.

A.7.2 The Computer Calculations

The computer calculation for the Sulfur Supply/Demand/Price Model consists of three elements:

(1) The LP input program.
(2) The LP calculation program.
(3) The LP output operational program.

A schematic diagram of how these three elements interact is shown in Figure 1. (See page 52)

(1) The LP Input Program

The input programs prepare three (3) sets of data cards in a format acceptable to the LP calculation program. The input programs accomplish this by selecting appropriate data from previously established data files and performing intermediate calculations to establish the supply availability, the demand requirements and constraints, and the delivered cost on a sulfur equivalent basis required for input to the LP calculation program.

(2) The LP Calculation Program

The LP calculation is accomplished using the Mathematical Optimization Subroutine System (1130 LP-MOSS). This subroutine is available from IBM for use with the IBM 1130 computer system. Additional information on this subroutine can be obtained from IBM by requesting application booklet H20-0345-2.

(3) The LP Output Operational Program

The LP output from the LP-MOSS subroutine is obtained on cards. The LP output operational program translates this card output into a matrix presentation with the supply regions as column elements and the demand regions as row elements. In addition, the output operational program stores selected results of the LP calculation in pre-established output data files.

A.7.3 Description of Specific Sulfur Model Programs

This section describes the LP input and the LP output operational programs developed specifically for the Sulfur Model.

PROGRAMS RRB07 to 10

This series of programs prepares the current solution output matrix from the LP report card. In addition to preparing the current solution output matrix, these programs stores the answers from the current solution in a set of data files. The data files include the sales of sulfur by various supply regions, the potential netback to the various supply regions and the delivered value for sulfur in the various demand regions. An additional data file which is required in using this program is the FOB cost file for calculating the true netback to the various supply regions based on the profit established in the LP solution. In application of this set of programs RRB07 is the main program which is called by the user. This program in turn calls RRB08, RRB09, and RRB10. The subroutine RPAQ is used and this subroutine in turn calls the subroutine RFILE. A function GEX is also used in the program.

SUBROUTINE RPAQ

Subroutine RPAQ is a versatile means of operating on the information contained in the 18 word per record files, containing 50 records, used in this system. The operation of this subroutine involves the search of a specified file to extract or to add values of the associated variable.

The transfer options available include:

1. The value of all the variables associated with a record name in the accessed file is replaced by the value of all the variables associated with the same record name in the program array.

2. The value of the variable associated with a record name in the accessed file for the time period N, is replaced by the value of the variable associated with the same record name in the array. In this option there is only one value of the associated variable in the array that is associated with the record name.

3. The inverse of option 2, namely, that the single value of the variable associated with a record name in the array is replaced by the value of the variable associated with the same record name in the accessed file for time period N.

4. The inverse of option 1, namely, that the value of all the variables associated with a record name in the array are replaced by the value of all the variables associated with the same record name in the accessed file.

A second option is provided concerning what to do with the information that has been transferred. These include:

1. Returning the information to the main program, and

2. Writing the new value of the variables associated with the record name into the originally accessed file.

This latter option is restricted to the use of transfer options 1 and 2 in which the original value of the variable associated with the record name in the accessed file has been replaced by values associated with the same record name in the array of the main program. In using this option the subroutine RFILE is called and the new file is written on the 1132 printer. The use of the subroutine RPAQ requires that the calling program contain a COMMON block, in which the first element of COMMON is the value NN, namely the year or time period for which the variable in the accessed file is to be extracted. This value, NN, is a number between 1 and 7.

The calling sequence for RPAQ is as follows (JJ, KK. LL, NAME3, N3, X3, NEXT) where JJ is the transfer option, KK is the number of the file to be accessed, LL is the second option, namely what to do with the data once it has been transferred, NAME3 is the name given the array containing the record names in the calling main program, N3 is the number of records contained in the main program array, X3 is the name of the variable array associated with the record name in the calling program, and NEXT is the incrementing variable for the file to be accessed.

SUBROUTINE RFILE

This subroutine is used to write a file record on the 1132 printer. The call statement of the subroutine is (N, JR) where N is the number of the file to be printed on the 1132 printer and JR is the name of the incrementing variable for the accessed file.

PROGRAM RRB12

This program prepares an 18 word per record data file containing the title of each record and associate values for seven different time periods. The use of this file requires the prior creation of an 18 word per record data file containing a maximum of 50 records for input of the information created by the program. Unused positions in the record are replaced with asterisks.

PROGRAM RRB15

This program calculates the delivered cost and prepares the cost cards for input to the LP MOSS linear program system. The use of this program requires access to three data files. Data file No. 1 is an 18 word per record file containing information on the FOB costs at all possible supply points for seven different time periods. Data file No. 2 is an 18 word per record file containing the transportation linkages and transportation costs. File No. 3 contains data on the acid equivalency value. It is an 18 word per record file.

PROGRAM RRB16

This program is used to prepare the supply and demand cards for use with the LP MOSS linear programming system. Use of this program requires access to an 18 word per record file containing 50 records, each record of which contains the name (or location) of a region for which supply or demand data is furnished for seven time periods.

This program calls subroutine RFIND.

SUBROUTINE RFIND

This subroutine obtains a file from the disc library and returns it to a main program array. It operates on an 18 word per record file, containing 50 records. The call statement of the subroutine is (A, NEXT, NAME, N, X) where A is the file number, NEXT is the incrementing variable on the file which is being called, NAME is the name given to the record titles that are brought to the main program array, N is the number of records which have been returned to the main program and X is the name given to the value of the seven associated variables in each file record when brought to the main program array. The value N is determined by subroutine RFIND and is returned to the main program for future use.

PROGRAM ARG 02

This program enables data to be read from an 18 word per record file containing 50 records.

A.7.4 Listing of Programs

The pages that follow are a "listing", i.e., a print-out, of the programs discussed in Section A.7.4. In sequence, the programs and subroutines are:

RRB 07 (2 pages)
RRB 08
RRB 09 (2 pages)
RRB 10
RPAQ
RFILE
FUNCTION GEX
RRB 12
RRB 15 (2 pages)
RRB 16
RFIND
ARG 02

The dates associated with the titles of these programs signify the data when each program was last checked or revised.

A.7.5 Instructions for LP Runs and Output

This section describes the use of the programs and includes a sample input and output, in tabular form, for each program.

PROGRAM RRB 12

The use of program RRB 12 requires the following input cards:

1. //bXEQb RRB 12 and a 1 in data field position 17.
2. *FILES (1, the name of the file to be entered)
3. The number of records in the file (right justified in data field positions 3 and 4)
4. A first file title in data field positions 1 to 36.
5. A second file title in data field positions 1 to 36.
6. Seven column headings specified by a letter in data field positions 4, 8, 12, 16, 20, 24 and 28.
7. A card for each file record with the following format: (1) The name of the record in data field position 1-8; (2) the value of the column elements in F5.2 notation with the decimal points in data field positions 18, 28, 38, 48, 58, 68 and 78.

A sample execution deck is given in Table 1. There is no output from RRB 12.

PROGRAM ARG 02

The use of program ARG 02 requires the following input cards:

1. //bXEQb ARG 02 and a 1 in data field position 17.
2. *FILES (1, the name of the file to be read).

The following is a sample execution deck for ARG 02:

```
         1         2         3         4         5         6         7         8
1234567890123456789012345678901234567890123456789012345678901234567890123456789
// XEQ ARG02      1
*FILES(1,MFD[illegible])
```

Sample output from ARG 02 is given in Table 2A to 2E.

PROGRAM RRB 16

The use of program RRB 16 requires the following input cards:

1. //bXEQb RRB 16 and a 1 in data field position 17.
2. *FILES(1, the name of the file to be accessed).
3. A card containing the following information: (a) the system bound for the LP run (in data field positions 1 to 8), (b) the file column from which the supply or demand data is to be taken (specified as 1 through 7 in data field position 11), and (c) a key specifying whether a supply or demand card is to be prepared (a 1 in data field position 20 indicates a supply card and a 2 in data field position 20 indicates a demand card).

The user is required to provide an adequate number of blank cards for the supply or demand cards to be punched following the last input card.

Sample Card Set-Up for Preparation of Demand Cards for LP Program Using RRB 16

```
         1         2         3         4         5         6         7        8
12345678901234567890123456789012345678901234567890123456789012345678901234589 0
//XEQ RRB16     1
*FILES(1,MFD20)
2020D     04
    (BLANK CARDS FOR PUNCHING)
```

The output from the demand portion of RRB 16 is a set of punched cards for input to LP-MOSS. A sample listing of such cards is given in Table 3.

The supply portion of the program is treated similarly as shown below and in Table 4.

<u>Sample Card Set-Up for Preparation of Supply Cards for LP Program Using RRB 16</u>

```
         1         2         3         4         5         6         7         8
1234567890123456789012345678901234567890123456789012345678901234578901234567890

// XEQ RRB16    1
*FILES(1,MFS20)
2020D    04
     (BLANK CARDS FOR PUNCHING)
```

PROGRAM RRB 15

The use of this program requires the following input cards:

1. //bXEQb RRB15 (Also a 4 in data field position 17).
2. *FILES (1, the name of the FOB cost file).
3. *FILES (2, the name of the transportation cost data file).
4. *FILES (3, the name of the acid equivalency value data file).
5. A card specifying the column from which the transportation cost data and the acid equivalency value is to be extracted (specified as a digit from 1 to 7 in data field position 11), and the column from which the FOB price data is to be extracted specified as a digit between 1 and 7 and located in data field position 21).
6. A card specifying the verbal description of the run in data field positions 1-20, and the year of the run in data field positions 25-28, and the case number in data field positions 33-37.

The user is required to provide an adequate number of blank cards for the cost cards to be punched following the last input card.

Sample Card Set-Up for Preparation of Cost Cards for LP Program Using RRB 15

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

// XEQ RRB15    1
*FILES(1, MFC20),(2,MFTRN),(3,MFEQ)
          7         4
                       2020     2020D
    (BLANK CARDS FOR PUNCHING)
```

RRB 15 provides a punched card output for input to LP-MOSS, and also a printed summary of the delivered cost of sulfur equivalent ($/LT of S equivalent). A sample is given in Tables 5A and 5B.

PROGRAM LP-MOSS

The execution of LP-MOSS requires:

1. A series of LP-MOSS control cards as specified in the IBM LP-MOSS Application Program booklet H20-0345-2. These control cards are underlined in the sample input deck that follows.
2. A set of activity cards for the LP run.
3. A set of supply cards prepared using RRB 16.
4. A set of demand cards prepared using RRB 16.
5. A set of cost cards prepared using RRB 15.
6. A series of blank cards on which the LP solution will be punched.

A sample of the LP-MOSS input deck is given in Table 6.

The output from LP-MOSS is a series of punched cards containing the LP solution data. The first two punched cards are title cards and are not used in subsequent computer processing of the data. The remainder of the punched cards are used as input to RRB 07. A sample output is given in Table 7.

PROGRAMS RRB 07 TO RRB 10

This series of programs prepares the current solution output matrix from the LP report cards. In using this program the following data input cards are required:

1. //bXEQb RRB 07 and a 4 in data field position 17.
2. Four file cards as follows:
   a) *FILES (2, the name of the output file to contain the delivered value).
   b) *FILES (3, the name of the output file to contain the sales).
   c) *FILES (4, the name of the output file to contain the supplier netback).
   d) *FILES (5, the name of the file containing the FOB cost).

3. A card containing the following information: the column of the FOB cost file from which the data for the current run are to be extracted (this is also the column of the output file that the output data is to be filed into), represented by a digit in data field position 11.

4. The report card deck obtained from the LP solution from which the top two cards containing the title of the LP solution report have been removed.

5. A blank card.

6. A card specifying the verbal description of the run in data field positions 1-20, and the year of the run in data field positions 25-28.

A sample input deck for RRB 07 is shown in Table 8.

Program RRB 07 operates on the LP solution to:

1. Prepare a matrix presentation of the LP solution.
2. Update the output files to include the result of the current LP run.

A sample of the matrix is given in Table 9. Samples of the three other output files are given in Tables 10-12.

A.7.6 Special Instructions

The use of the computational programs requires a consideration of two additional elements:

1. The nomenclature allowed.
2. Preparation of activity cards for input to LP-MOSS.

1. Nomenclature Allowed

The NAME assigned to a supply or demand region is limited to eight characters (blanks are allowed characters), the first four of which must be unique to a given supply or demand region. The term REGION in this connotation includes any sub-regions that may be used in formulating the problem. An example follows:

NAME	$	C	O	A	T	M	E	X

$$\underbrace{1\ 2\ 3\ 4}_{\text{Unique}}\ 5\ 6\ 7\ 8$$

The first character of the NAME of SUPPLY REGIONS must be either an asterisk (*) or a dollar sign ($). An asterisk signifies that the supply region is an acid supply point. A dollar sign signifies that the supply region is an elemental sulfur supply point. Examples include:

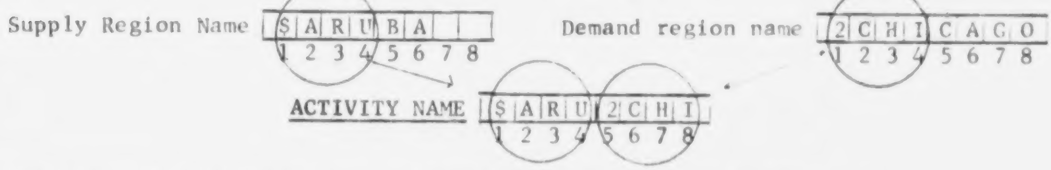
	1	2	3	4	5	6	7	8	
NAME	*	S	U	D	B	U	R	Y	Acid supply point
NAME	$	A	R	U	B	A			Elemental sulfur supply point

The first character of the NAME of DEMAND REGIONS must be either a pound sign (#) or a numeral. The pound sign is associated with the region's total demand; numerals 1, 2 or 3 signify a sub-demand region in which a lower bound of sulfur equivalent from a given supply point is desired; and numerals 5 or 6 signify a sub-demand region in which an upper bound on sulfur as acid from a given supply point is desired. Examples include:

	1	2	3	4	5	6	7	8	
NAME	#	C	H	I	C	A	G	O	Total Demand in Chicago region
NAME	2	C	H	I	C	A	G	O	Lower bound on sulfur equivalent
NAME	6	S	U	D	B	U	R	Y	Upper bound on sulfur equivalent as acid received from acid supply point SUDBURY

In selecting the demand sub-region nomenclature, the user will find it convenient to assign a given number to a given supply point, e.g., *SUDBURY has been assigned the numeral 6 in demand sub-region supply allocations.

The first four characters of the NAME of an ACTIVITY consist of the first four characteris of the supply region name, and the second four characters of the NAME of an ACTIVITY consist of the first four characteris of the demand region name, e.g.,:



The ACTIVITY NAMES are used in preparing the ACTIVITY CARDS, and are used also as the record name in the Transportation Cost FILE.

2. Preparation of Activity Cards

A set of activity cards which define the interaction constraints must be constructed for input to the LP-MOSS program.

For each ACTIVITY the following cards with entries in the designated data field positions are required:

	1st Name	2nd Name	VALUE
(a)	ACTIVITY NAME	ASSOCIATED SUPPLY REGION NAME	
	$ A R U 2 C H I	$ A R U B A	1 . 0
	5 6 7 8 9 10 11 12	15 16 17 18 19 20 21 22	29 30 31
	Data field position		
(b)	ACTIVITY NAME	ASSOCIATED DEMAND SUB-REGION NAME	
	$ A R U 2 C H I	2 C H I C A G O	1 . 0
(c)	ACTIVITY NAME	ASSOCIATED TOTAL DEMAND REGION NAME	
	$ A R U 2 C H I	# C H I C A G O	1 . 0

If there is no demand sub-region card (B) is omitted.

PROGRAM RKB07 (1130 COMPUTER, 9/29/71)

```
// FOR
*LIST SOURCE PROGRAM
**PROGRAM RRB07
*IOCS(CARD,1132 PRINTER)
*ONE WORD INTEGERS
      DATA IASCT/'*'/
      DATA IEQ/'EQ'/
      DATA IDOL /'$' /
C    POUND SIGN
      DATA IPND /31552 /
      DATA ICO,IST/'CO','ST'/
      DIMENSION KARAY(9),JCARD(1),KCARD(2)
      COMMON IYEAR,KO,KBLAN,NC,NR,TCOST
      COMMON LINK(200,4)
      COMMON ICOL(30,4),PROFT(30)
      COMMON PRICE(30),SALES(30),IROW(30,4)
      COMMON BND(200),COST(200),ACTIV(200),REDC(200),SUPLY(30),DEM(30)
      COMMON VALUE(30,30,3)
      COMMON DUPY (60)
      DO 1 J = 1,4
      DO 1 I = 1,30
    1 ICOL (I,J) = KBLAN
      DO 2 I=1,30
      SALES(I)=100001.
      SUPLY(I)=100001.
      PROFT(I)=100001.
      DO 2 J=1,30
      DO 2 K=1,3
      VALUE(I,J,K)= 100001.
    2 CONTINUE
      IN=2
      KO=3
      KBLAN=16448
      NO=0
      NR=0
      NC=0
      READ(IN,5) IYEAR
    5 FORMAT(9X,I2)
      DO 250 I=1,200
      READ(IN,10)(LINK(I,J),J=1,4),KEY,KODE,ACTIV(I),KARAY,COST(I),REDC(I)
     1I)
   10 FORMAT(1X,4A2,A2,3X,I1,3X,F10.3,2X,6A1,1X,3A1,14X,F10.3,2X,F10.3)
      IF(KARAY(1)-IASCT)130,120,130
  120 BND(I)=0.0
      GO TO 140
  130 BND(I)=GEX(KARAY)
  140 IF (LINK(I,1)-KBLAN)150,260,150
  150 NO=NO+1
      JCARD(1)=LINK(I,1)
      CALL UNPAC (JCARD,1,1,KCARD,1)
      IF(KODE)250,180,250
  180 IF(LINK(I,1)-ICO)200,185,200
  185 IF(LINK(I,2)-IST)200,190,200
  190 TCOST=ACTIV(I)
      GO TO 250
  200 IF(KEY-IEQ)205,203,205
203   IF( KCARD(1) - IDOL) 204, 230, 204
204   IF( KCARD(1) - IASCT) 210, 230, 210
```

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```
205   IF( KCARD(1) - IBND) 206, 210, 206
206   IF (KCARD(1)) 210,210,230
  210 NR=NR+1
      DO 220 J=1,4
      IROW(NR,J)=LINK(I,J)
      PRICE(NR)=-REDC(I)+0.001
      DEM(NR)=BND(I)+0.001
  220 CONTINUE
      GO TO 250
  230 NC=NC+1
      DO 240 J=1,4
      ICOL(NC,J)=LINK(I,J)
      SUPLY(NC)=BND(I)+0.001
      SALES(NC)=ACTIV(I)+0.001
      PROFT(NC)=-REDC(I)+0.001
  240 CONTINUE
  250 CONTINUE
  260 DO 420 M=1,NR
      DO 410 I=1,NO
      IF (IROW(M,1)-LINK(I,3))410,300,410
  300 IF (IROW(M,2)-LINK(I,4))410,320,410
  320 DO 400 N=1,NC
      IF (ICOL(N,1)-LINK(I,1))400,330,400
  330 IF (ICOL(N,2)-LINK(I,2))400,340,400
  340 VALUE(M,N,1)=ACTIV(I)+0.001
      VALUE(M,N,2)=COST(I)+0.001
      VALUE(M,N,3)=REDC(I)-0.001
      GO TO 410
  400 CONTINUE
  410 CONTINUE
  420 CONTINUE
      CALL LINK(RRR08)
      END
// DUP
*DELETE                 RRR07
*STORE          WS  UA  RRR07
```

PROGRAM RRB08 (1130 COMPUTER, 9/21/71)

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```
// FOR
*LIST SOURCE PROGRAM
**PROGRAM RRB08
*ONE WORD INTEGERS
*IOCS(CARD,1132 PRINTER)
*IOCS(DISK)
      DIMENSION INEW(46,4),X3(46,7)
      COMMON IYEAR,KO,KPLAN,NC,NR,TCOST
      COMMON CFOB(33,12),DUMMY(4)
      COMMON ICOL(30,4),PROFT(30)
      COMMON PRICE(30),SALES(30),IROW(30,4)
      COMMON RND(200),COST(200),ACTIV(200),REDC(200),SUPLY(30),DEM(30)
      COMMON VALUE(30,30,3)
      COMMON POTNB(30),CFOB1(30)
      DEFINE FILE 5(50,18,U,NEXT5)
      DO 40 I = 1,30
      CFOB1(I) = 100001.
      POTNB (I) = 100001.
   40 CONTINUE
      DO 5 I=1,46
      DO 5 J=1,7
      X3(I,J)=0.0
    5 CONTINUE
      N3=NR
      DO 10 J=1,4
      DO 10 I=1,30
      INEW(I,J)=ICOL(I,J)
   10 CONTINUE
      CALL RPAQ  (3,5,1,INEW,N3,X3,NEXT5)
      DO 30 I=1,30
   20 CFOB1(I)=X3(I,1)
      POTNB(I)=PROFT(I) + CFOB1(I) +0.001
      IF (SALES(I)-.0011)25,25,30
   25 POTNB(I)=100001.
      PROFT(I)=100001.
   30 CONTINUE
      CALL LINK(RRB09)
      END
// DUP
*DELETE             RRB08
*STORE      WS  UA  RRB08
```

PROGRAM RRB09 (1130 COMPUTER, 9/27/71)

```
// FOR
**PROGRAM RRB09
*ONE WORD INTEGERS
*IOCS(CARD,1132 PRINTER)
      DIMENSION NAME2(10)
      COMMON IYEAR,KO,KPLAN,NC,NR,TCOST
      COMMON CFOB(33,12),DUMMY(4)
      COMMON ICOL(30,4),PROFT(30)
      COMMON PRICE(30),SALES(30),IROW(30,4)
      COMMON BND(200),COST(200),ACTIV(200),REDC(200),SUPLY(30),DEM(30)
      COMMON VALUE(30,30,3)
      COMMON POTNB(30),CFOB1(30)
      DATA IN/2/
      READ (IN,10) NAME2,JYEAR
   10 FORMAT(10A2,4X,I4)
      WRITE (KO,15) NAME2,JYEAR
   15 FORMAT (1H1,T3,'PROBLEM NAME-',10A2//T3,'YEAR-',I4//////)
      WRITE(KO,18)
   18 FORMAT(1X,T3,'DATA OUTPUT FORMAT ')
      WRITE (KO,20)
   20 FORMAT(1X,T35,'DEMAND REGION',T70,'SUPPLY REGION'/T35,'******
     1*******',T70, '***************'//T70,'TRANSACTION(MM LONG TONS)'
     2          //T35'TOTAL DEMAND(MM LONG TONS)',T70,'DELIVERED VALUE',
     3  '($/TON)'//T35,'CALCULATED TRADING PRICE($/TON)',T70,'COST CHANG
     4E REQUIRED TO CAUSE'/T70, 'ACTIVITY TO BECOME ACTIVE($/TON)')
      WRITE (KO,60)TCOST
      K=1
      L=10
  480 WRITE(KO,25)
   25 FORMAT(1H1,T2'DEMAND',T10'**********************************
     1SUPPLY REGIONS**************************************
     2'/T2'REGIONS'//)
  490 WRITE(KO,30)((ICOL(N,J),J=1,4),N=K,L)
   30 FORMAT(/10X,10(2X,4A2))
      DO 520M=1,NR
      WRITE (KO,40)(IROW(M,J),J=1,4),(VALUE(M,N,1),N=K,L)
   40 FORMAT(/2X,4A2,10(3X,F7.2))
      WRITE(KO,50)DEM(M),(VALUE(M,N,2),N=K,L)
   50 FORMAT(11(3X,F7.2))
      WRITE(KO,55)PRICE(M),(VALUE(M,N,3),N=K,L)
   55 FORMAT(11(3X,F7.2))
  520 CONTINUE
      WRITE(KO,80)
   80 FORMAT(/2X,6HTOTALS)
      WRITE(KO,70)(SALES(N),N=K,L)
   70 FORMAT(1X,5HSALES,3X,10(3X,F7.2))
      WRITE(KO,90)(SUPLY(N),N=K,L)
   90 FORMAT (1X,6HSUPPLY,2X,10(3X,F7.2))
      WRITE(KO,92)(CFOB1(N),N=K,L)
   92 FORMAT(1X,8HCOST FOB,10(3X,F7.2))
      WRITE(KO,93)(PROFT(N),N=K,L)
   93 FORMAT(1X,6HPROFIT,2X,10(3X,F7.2))
      WRITE(KO,95)(POTNB(N),N=K,L)
   95 FORMAT (1X,8HNET-BACK,10(3X,F7.2))
      K=K+10
      L=L+10
      IF(L-NC)620,620,600
  600 IF(L-NC-10)610,630,630
```

PROGRAM RRR09 (1130 COMPUTER, 9/27/71)

```
   610 L=NC
   620 GO TO 480
   630 CONTINUE
    60 FORMAT(     ///' TOTAL COST THIS PROBLEM',2X,F10.3,'( $ MILLIONS)')
       CALL LINK(RRR10)
       END
// DUP
*DELETE              RRR09
*STORE       WS  UA  RRR09
```

PROGRAM RRB10 (1130 COMPUTER, 9/21/71)

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```
// FOR
*LIST SOURCE PROGRAM
**PROGRAM RRB10
*IOCS(CARD,1132 PRINTER)
*ONE WORD INTEGERS
*IOCS(DISK)
      DIMENSION INEW(46,4),X3(46,7)
      COMMON IYEAR,KO,KPLAN,NC,NR,TCOST
      COMMON CFOR(33,12),DUMMY(4)
      COMMON ICOL(30,4),PROFT(30)
      COMMON PRICE(30),SALES(30),IROW(30,4)
      COMMON BND(200),COST(200),ACTIV(200),REDC(200),SUPLY(30),DEM(30)
      COMMON VALUE(30,30,3)
      COMMON POTNB(30)
      DATA X3/322*0.0/
      DEFINE FILE 2(50,18,U,NEXT2)
      DEFINE FILE 3(50,18,U,NEXT3)
      DEFINE FILE 4(50,18,U,NEXT4)
      N3=NR
      DO 10 J=1,4
      DO 10 I=1,30
      INEW(I,J)=IROW(I,J)
   10 CONTINUE
      DO 20 I=1,30
      X3(I,1)=PRICE(I)
   20 CONTINUE
      CALL RPAQ  (2,2,2,INEW,N3,X3,NEXT2)
      N3=NC
      DO 30 J=1,4
      DO 30 I=1,30
      INEW(I,J)=ICOL(I,J)
   30 CONTINUE
      DO 40 I=1,30
      X3(I,1)=SALES(I)
   40 CONTINUE
      CALL RPAQ(2,3,2,INEW,N3,X3,NEXT3)
      DO 50 I=1,30
      X3(I,1)=POTNB(I)
   50 CONTINUE
      CALL RPAQ  (2,4,2,INEW,N3,X3,NEXT4)
      CALL EXIT
      END
// DUP
*DELETE             RRB10
*STORE      WS  UA  RRB10
```

PROGRAM RRB12 (1130 COMPUTER, 9/15/71)

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```
// FOR
*ONE WORD INTEGERS
**PROGRAM RRB12
*IOCS(CARD,1132 PRINTER)
*IOCS(DISK)
      DIMENSION TITLE(3,9), LOCL(46,4),X(46,7)
      DEFINE FILE 1(50,18,U,JR)
      DATA TITLE/27*' '/
      DATA LOCL/184*' '/
      DATA X/322*0.0/
      IN=2
      JR=1
      READ(IN,10)  NR
   10 FORMAT(2X,I2,2X,I2)
      WRITE(1'JR) NR
      DO 30  K=1,3
      READ(IN,20) (TITLE(K,L),L=1,9)
   20 FORMAT( 9A4)
      WRITE(1'JR) (TITLE(K,L),L=1,9)
   30 CONTINUE
      DO 50  I=1,NR
      READ(IN,40) (LOCL(I,J),J=1,4),(X(I,J),J=1,7)
   40 FORMAT(4A2,2X,7F10.2)
      DO 45 J=1,7
      IF(X(I,J))45,42,45
   42 X(I,J)=100001.
   45 CONTINUE
   48 WRITE(1'JR) (LOCL(I,J),J=1,4),(X(I,J),J=1,7)
   50 CONTINUE
      NNR = NR+1
      DO 60 I=NNR,46
      WRITE(1'JR)(LOCL(I,J),J=1,4),(X(I,J),J=1,7)
   60 CONTINUE
      CALL EXIT
      END
// DUP
*DELETE               RRB12
*STORE       WS  UA   RRB12
```

PROGRAM RRP15 (1130 COMPUTER, 9/30/71)

```
// FOR
*ONE WORD INTEGERS
*IOCS(CARD,1132 PRINTER)
*IOCS(DISK)
**PROGRAM RRP15
      DIMENSION NAME2(10), CRED(47,7)
      DIMENSION LOCL(47,4), CFOB(47,7), ILINK(47,4), TRAN(47,7)
      DIMENSION TCFOB(47), TRCST(47), TTOT(47)
      DIMENSION JCARD(1), KCARD(2), LOC2(47,4)
      DATA IN,KO,KBLAN/2,3,' '/
      DATA ICENT / '*' /
      DEFINE FILE 1(50,18,U,NEXT1)
      DEFINE FILE2( 50,15,U,NEXT2)
      DEFINE FILE 3(50,15,U,NEXT3)
C    IYEAR = NO. OF COL. IN YEAR FILE
C    KROW = NO. OF COL. IN COST FILE
      READ(IN, 9)IYEAR, KROW
    9 FORMAT (9X,I2, 8X, I2)
      READ (IN,10) NAME2,JYEAR, JCASE
   10 FORMAT(10A2,4X,I4, 4X, 5A1)
      WRITE (KO,15) NAME2,JYEAR, JCASE
   15 FORMAT (1H1,T3,'PROBLEM NAME-',10A2//T3,'YEAR-',I4//
     1    T3,'CASE--',5A1////)
      WRITE (KO,45)
   45 FORMAT (1X,//////T20,'CALCULATION OF MINIMUM DELIVERED COST-$/LT')
      WRITE(KO,5)
    5 FORMAT(1H1)
      WRITE (KO,46)
   46 FORMAT (1X,'TRADE LINK'T15,'FOB'T30,'TRANSPORTATION'//)
      N1=0
      NEXT 1=5
      DO 155 I=1,47
      READ(1'NEXT1)(LOCL(I,J),J=1,4),(CFOB(I,J),J=1,7)
      IF (LOCL(I,1)-KBLAN) 150,160,150
  150 N1=N1+1
      DO 155 J=1,7
      IF(CFOB(I,J)-100001.)155,152,155
  152 CFOB(I,J)=0.
  155 CONTINUE
  160 N2=0
      NEXT2=5
      DO 185 I=1,47
      READ(2'NEXT2)(ILINK(I,J),J=1,4), (TRAN(I,K),K=1,7)
      IF(ILINK(I,1)-KBLAN)180,190,180
  180 N2=N2+1
      DO 182 K=1,7
      IF( TRAN(I,K) - 100001. ) 182, 181, 182
181   TRAN(I,K) = 0.0
182   CONTINUE
  185 CONTINUE
190   N3 = 0
      NEXT3 = 5
      DO 230 K=1,47
      READ(3'NEXT3) (LOC2(K,J),J=1,4),(CRED(K,J),J=1,7)
      IF( LOC2(K,1) - KBLAN) 215, 240, 215
215   N3 = N3 + 1
230   CONTINUE
  240 DO 390 I=1,N2
```

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```
      DO 325 K=1,N1
      IF (ILINK(I,1)-LOCL(K,1))310,300,310
  300 IF (ILINK(I,2)-LOCL(K,2))310,320,310
  310 GO TO 325
  320 TCFOR(I)=CFOR(K,KROW)
      GO TO 330
  325 CONTINUE
330   TRCST(I) = TRAN(I,IYEAR)
      TTOT(I)=TRCST(I)+TCFOR(I)
      JCARD(1) = ILINK(I,1)
      CALL UNPAC( JCARD, 1, 1, KCARD, 1 )
      IF( ICENT - KCARD(1) ) 390, 340, 390
  340 DO 350 JJ = 1,N3
      IF (ILINK(I,1) - LOC2(JJ,1))350,343,350
  343 IF (ILINK(I,2)-LOC2(JJ,2)) 350,348,350
  348 TTOT(I)=TTOT(I)-CRED(JJ,IYEAR)
      GO TO 390
  350 CONTINUE
  390 CONTINUE
      READ(IN,49)
   49 FORMAT (1A2)
      DO 400 I=1,N2
      WRITE(KO,20)(ILINK(I,J),J=1,4),TCFOR(I),TRCST(I),          TTOT(I)
   20 FORMAT(1X,4A2,3(10X,F5.2))
      WRITE(IN,30)(ILINK(I,J),J=1,4),TTOT(I)
      CALL STACK
   30 FORMAT(4X,4A2,2X,4HCOST,6X,F8.2)
  400 CONTINUE
      CALL EXIT
      END
// DUP
*DELETE             RRB15
*STORE       WS  UA  RRB15
```

PROGRAM RRB16 (1130 COMPUTER, 9/17/71)

```
*IOCS(DISK)
*ONE WORD INTEGERS
*NAME RRB16
**PROGRAM RRB16
      DIMENSION LOCL(47,4),X(47, 7),IBOUN(4)
      DIMENSION JCARD(1), KCARD(2)
      DEFINE FILE 1 (50,15,U,JREC)
C---POUND SIGN (NUMBER SIGN)
      DATA IPOUN / 31552 /
      IN=2
      READ (IN,10) IBOUN,IYEAR,KEY
   10 FORMAT(4A2,1X,I2,8X,I1)
      CALL RFIND(1,JREC,LOCL,N,X)
      READ(IN,12) IDMY
   12 FORMAT(I2)
   15 GO TO (20,35),KEY
   20 WRITE(IN,60)IBOUN
      CALL STACK
   22 DO 30 I=1,N
      IF(X(I,IYEAR)-100001.)25,23,25
   23 X(I,IYEAR)=0.
   25 WRITE(IN,52) IBOUN,(LOCL(I,J),J=1,4),X(I,IYEAR)
      CALL STACK
   30 CONTINUE
      GO TO 70
   35 DO 45 I=1,N
      IF(X(I,IYEAR)-100001.) 37, 36, 37
36    X(I,IYEAR)=0.
37    JCARD(1) = LOCL(I,1)
      CALL UNPAC( JCARD, 1, 1, KCARD, 1 )
      ICOL1 = KCARD(1)
C---1,2,3--GO TO 40 (LR)
C    5,6--GO TO 39 (UR)
C   POUND SIGN--GO TO 41 (FX)
      IF( ICOL1 - IPOUN ) 38, 41, 38
38    IF( ICOL1 + 3100 ) 40, 39, 39
39    WRITE( IN, 52 ) IBOUN, (LOCL(I,J),J=1,4), X(I,IYEAR)
      CALL STACK
      GO TO 45
40    WRITE( IN, 51 ) IBOUN, (LOCL(I,J),J=1,4), X(I,IYEAR)
      CALL STACK
      GO TO 45
   41 WRITE(IN,50)IBOUN,(LOCL(I,J),J=1,4),X(I,IYEAR)
      CALL STACK
   45 CONTINUE
   70 CALL EXIT
   50 FORMAT(1X,2HFX,1X,4A2,2X,4A2,2X,F8.2)
51    FORMAT( 1X, 2HLR, 1X, 4A2, 2X, 4A2, 2X, F8.2 )
52    FORMAT( 1X, 2HUR, 1X, 4A2, 2X, 4A2, 2X, F8.2 )
   60 FORMAT(1X,2HER,1X,4A2,2X,4HCOST)
      END

// DUP
*DELETE              RRB16
*STORE       WS  UA  RRB16
```

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PROGRAM ARG02 (1130 COMPUTER, 9/27/71)

```
// FOR
*ONE WORD INTEGERS
*IOCS(CARD,1132 PRINTER)
*IOCS(DISK)
*NAME ARG02
      DIMENSION TITLE(3,9), LOCL(46,4),X(46,7)
      DATA TITLE/27*' '/
      DATA LOCL/184*' '/
      DATA X/322*1.E05/
      DEFINE FILE 1(50,18,U,JR)
      KO=3
      JR=1
      READ(1'JR)  NR
      WRITE(KO,20)
   20 FORMAT(1H1)
      DO 30  K=1,3
      READ(1'JR)  (TITLE(K,L),L=1,9)
   30 CONTINUE
      WRITE(KO,40) (TITLE(1,L),L=1,9)
   40 FORMAT(43X, 9A4,/)
      WRITE(KO,41) (TITLE(2,L),L=1,9)
41    FORMAT(47X, 9A4///)
      WRITE(KO,42) (TITLE(3,L), L=1,9)
42    FORMAT(12X,9(6X,A4))
85    DO 180  I=1,NR
      READ(1'JR) (LOCL(I,J),J=1,4),(X(I,J),J=1,7)
      WRITE(KO,90) (LOCL(I,J),J=1,4),(X(I,J),J=1,7)
   90 FORMAT(1X,4A2,4X, 7(5X,F5.2))
  180 CONTINUE
      CALL EXIT
      END
// DUP
*DELETE             ARG02
*STORE      WS  UA  ARG02
```

SUBROUTINE RFILE (1130 COMPUTER, 9/21/71)

```
// FOR
*ONE WORD INTEGERS
*LIST SOURCE PROGRAM
**SUBROUTINE RFILE
      SUBROUTINE RFILE(N,JR)
      DIMENSION TITLE(3,9), LOCL(46,4),X(46,7)
      DATA TITLE/27*'  '/
      DATA LOCL/184*'  '/
      DATA X/322*1.E05/
      KO=3
      JR=1
      READ(N'JR)  NR
      WRITE(KO,20)
   20 FORMAT(1H1)
      DO 30  K=1,3
      READ(N'JR)  (TITLE(K,L),L=1,9)
   30 CONTINUE
      WRITE(KO,40) (TITLE(1,L),L=1,9)
   40 FORMAT(43X, 9A4,/)
      WRITE(KO,41) (TITLE(2,L),L=1,9)
41    FORMAT(47X, 9A4///)
      WRITE(KO,42) (TITLE(3,L), L=1,9)
42    FORMAT(7X, 9(6X,A4))
85    DO 180  I=1,NR
      READ(N'JR) (LOCL(I,J),J=1,4),(X(I,J),J=1,7)
      WRITE(KO,90) (LOCL(I,J),J=1,4),(X(I,J),J=1,7)
   90 FORMAT(1X,4A2,4X, 7(5X,F5.2))
  180 CONTINUE
      RETURN
      END
// DUP
*DELETE               RFILE
*STORE      WS  UA    RFILE
```

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SUBROUTINE REIND (1130 COMPUTER, 9/16/71)

```
// FOR
*ONE WORD INTEGERS
**SUBROUTINE REIND
      SUBROUTINE REIND(A,NEXT,NAME,N,X)
      INTEGER A
      DIMENSION NAME(47,4),X(47,7)
      KBLAN=16448
      N=0
      NEXT=5
      DO 25 I=1,47
      READ(A'NEXT)(NAME(I,J),J=1,4),(X(I,J),J=1,7)
      IF(NAME(I,1)-KBLAN)20,30,20
   20 N=N+1
   25 CONTINUE
   30 RETURN
      END
// DUP
*DELETE             REIND
*STORE      WS  UA  REIND
```

PROGRAM RPAQ (1130 COMPUTER, 9/23/71)

```
// FOR
*ONE WORD INTEGERS
**SUBROUTINE RPAQ
      SUBROUTINE RPAQ (JJ,KK,LL,NAME3,N3,X3,NEXT)
      DATA KBLAN/' '/
      DIMENSION  NAME4(46,4),NAME3(46,4),X3(46,7),X4(46,7)
      COMMON NN
      KO=3
      N4=0
   45 NEXT=5
      DO 55I=1,46
      READ(KK'NEXT)(NAME4(I,J),J=1,4),(X4(I,J),J=1,7)
      IF (NAME4(I,1)-KBLAN)50,60,50
   50 N4=N4+1
   55 CONTINUE
   60 DO 150 K=1,N4
      DO 148 I=1,N3
      IF(NAME4(K,1)-NAME3(I,1))148,90,148
   90 IF(NAME4(K,2)-NAME3(I,2))148,100,148
  100 IF(NAME4(K,3)-NAME3(I,3))148,110,148
  110 IF(NAME4(K,4)-NAME3(I,4))148,130,148
  130 GO TO (135,140,141,142),JJ
  135 DO 138 J=1,7
      X4(K,J)=X3(I,J)
  138 CONTINUE
      GO TO 150
  140 X4(K,NN)=X3(I,1)
      GO TO 150
  141 X3(I,1)=X4(K,NN)
      GO TO 150
  142 DO 144 J=1,7
      X3(I,J)=X4(K,J)
  144 CONTINUE
      GO TO 150
  148 CONTINUE
  150 CONTINUE
      GO TO (160,162),LL
  160 GO TO 170
  162 NEXT=5
      DO 163 I=1,N4
      WRITE(KK'NEXT)(NAME4(I,J),J=1,4),(X4(I,J),J=1,7)
  163 CONTINUE
      CALL REFILE(KK,NEXT)
  170 RETURN
      END
// DUP
*DELETE             RPAQ
*STORE      WS  UA  RPAQ
```

FUNCTION GEX (1130 COMPUTER)

```
// FOR
*ONE WORD INTEGERS
*LIST SOURCE PROGRAM
      FUNCTION GEX(KARAY)
      DIMENSION CARAY(9)
      DIMENSION KARAY(9),PARAY(9)
      DATA PARAY/100000.,10000.,1000.,100.,10.,1.,.1,.01,.001/
      DO 10 I=1,9
      K=(KARAY(I)+4032)/256
      IF (K-80)10,9,10
    9 K=0
   10 CARAY(I)=FLOAT(K)
      GEX=0.
      DO 20 I=1,9
   20 GEX=GEX+PARAY(I)*CARAY(I)
      RETURN
      END
// DUP
*DELETE             GEX
*STORE      WS  UA  GEX
```

APPENDIX 7

TABLE 1

SAMPLE EXECUTION DECK FOR PROGRAM RRB 12

```
                       CREATE AND PRINT EXTRA-REGIONAL SUPPLY FILE                         1
// XEQ RRB12    1
*FILES(1,MES80)
  10
1980 EXTRA-REGIONAL SUPPLY
10-28-71
   A   B   C   D   E   F   G
*TUCSON              .20        .20        .20        .20        .20        .20        .20
$ORLEANS            6.00       5.50       5.25       5.00       4.75       4.50       5.25
$COATMEX             .50        .50        .50        .50        .50        .50        .50
$ARUBA              1.10       1.10       1.10       1.10       1.10       1.10       1.10
$CALGARY            8.00       8.00       8.00       8.00       8.00       8.00       8.00
*SUDBURY             .90        .90        .90        .90        .90        .90        .90
$CHICAGO             .00        .00        .00        .00        .00        .00        .00
$NEWARK              .00        .00        .00        .00        .00        .00        .00
$MEMPHIS             .00        .00        .00        .00        .00        .00        .00
$FRISCO              .00        .00        .00        .00        .00        .00        .00
```

APPENDIX 7

TABLE 2

SAMPLE OUTPUT FROM PROGRAM ARG 02

```
                                   TABLE 2A - 1980 EXTRA-REGIONAL SUPPLY

                                                 10-28-71


                         A          B          C          D          E          F          G
*TUCSON                0.20       0.20       0.20       0.20       0.20       0.20       0.20
$ORLEANS               6.00       5.50       5.25       5.00       4.75       4.50       5.25
$COATMEX               0.50       0.50       0.50       0.50       0.50       0.50       0.50
$ARUBA                 1.10       1.10       1.10       1.10       1.10       1.10       1.10
$CALGARY               8.00       8.00       8.00       8.00       8.00       8.00       8.00
*SUDBURY               0.90       0.90       0.90       0.90       0.90       0.90       0.90
$CHICAGO              *****      *****      *****      *****      *****      *****      *****
$NEWARK               *****      *****      *****      *****      *****      *****      *****
$MEMPHIS              *****      *****      *****      *****      *****      *****      *****
$FRISCO               *****      *****      *****      *****      *****      *****      *****
```

APPENDIX 7

TABLE 2B - 1980 FOB COST

10-28-71

	A	B	C	D	E	F	G
*TUCSON	1.00	0.01	0.01	0.01	0.01	0.01	0.01
$ORLEANS	22.00	21.00	20.00	19.00	18.50	17.00	20.00
$COATMEX	22.00	21.00	22.00	20.00	19.50	20.00	21.00
$ARUBA	20.00	18.00	16.50	15.00	13.50	15.00	16.50
$CALGARY	11.00	10.00	9.50	9.00	8.50	5.00	8.00
*SUDBURY	13.70	13.70	13.70	13.70	13.70	13.70	13.70
$CHICAGO	*****	*****	*****	*****	*****	*****	*****

APPENDIX 7

TABLE 2C - 1980 REGIONALIZED DEMAND

10-28-71

	A	B	C	D	E	F	G
BOSTON	0.09	0.08	0.07	0.05	0.04	0.01	0.04
1BOSTON	0.02	0.02	0.02	0.02	0.02	*****	*****
2BOSTON	*****	*****	*****	*****	*****	*****	*****
NEWARK	0.64	0.59	0.47	0.36	0.24	0.01	0.24
1NEWARK	0.15	0.15	0.15	0.15	0.10	*****	*****
2NEWARK	0.10	0.10	0.10	0.10	0.05	*****	*****
6NEWARK	0.06	0.06	0.05	0.04	0.02	0.01	0.02
NORFOLK	0.96	0.91	0.81	0.71	0.61	0.41	0.61
1NORFOLK	0.25	0.25	0.25	0.25	0.25	0.20	*****
2NORFOLK	0.10	0.10	0.10	0.10	0.10	*****	*****
CHICAGO	1.15	1.07	0.58	0.11	0.01	0.01	0.01
3CHICAGO	0.60	0.50	0.20	0.05	*****	*****	*****
6CHICAGO	0.10	0.10	0.05	0.02	*****	0.01	0.01
MEMPHIS	0.42	0.38	0.26	0.14	0.02	*****	0.02
OMAHA	0.22	0.21	0.14	0.07	0.01	*****	0.01
3OMAHA	0.20	0.19	0.12	0.05	*****	*****	*****
SEATTLE	0.22	0.20	0.20	0.20	0.20	0.20	0.20
LANG.CA	0.18	0.14	0.14	0.14	0.14	0.14	0.14
5LANG.CA	0.01	0.01	0.01	0.01	0.01	0.10	0.01
TAMPA	3.25	3.09	3.07	3.04	3.02	2.97	3.02
1TAMPA	2.40	2.40	2.40	2.40	2.40	1.00	*****
2TAMPA	*****	*****	*****	*****	*****	*****	*****
ROTT'DM	1.60	1.60	1.60	1.60	1.60	1.60	1.60
1ROTT'DM	0.60	0.60	0.60	0.60	0.60	*****	*****
2ROTT'DM	0.15	0.15	0.15	0.15	0.15	*****	*****
3ROTT'DM	0.50	0.50	0.50	0.50	0.50	*****	*****
6ROTT'DM	0.15	0.15	0.15	0.15	0.15	0.15	0.15

APPENDIX 7

TABLE 2D - TRANSPORTATION COST FILE

1

	A	B	C	D	E	F	G
$ORL1BOS	6.66	6.66	6.66	6.66	6.66	6.66	6.66
$ORL1NEW	5.99	5.99	5.99	5.99	5.99	5.99	5.99
$ORL1NOR	5.48	5.48	5.48	5.48	5.48	5.48	5.48
$ORL=CHI	4.21	4.21	4.21	4.21	4.21	4.21	4.21
$ORL=MEM	2.05	2.05	2.05	2.05	2.05	2.05	2.05
$ORL=OMA	4.51	4.51	4.51	4.51	4.51	4.51	4.51
$ORL1TAM	1.80	1.80	1.80	1.80	1.80	1.80	1.80
$ORL1ROT	6.40	6.40	6.40	6.40	6.40	6.40	6.40
$COA2BOS	3.04	3.04	3.04	3.04	3.04	3.04	3.04
$COA2NEW	2.77	2.77	2.77	2.77	2.77	2.77	2.77
$COA2NOR	2.56	2.56	2.56	2.56	2.56	2.56	2.56
$COA2TAM	1.62	1.62	1.62	1.62	1.62	1.62	1.62
$COA2ROT	6.67	6.67	6.67	6.67	6.67	6.67	6.67
$ARU=BOS	4.28	4.28	4.28	4.28	4.28	4.28	4.28
$ARU=NEW	4.03	4.03	4.03	4.03	4.03	4.03	4.03
$ARU=NOR	3.84	3.84	3.84	3.84	3.84	3.84	3.84
$ARU=TAM	3.65	3.65	3.65	3.65	3.65	3.65	3.65
$ARU=ROT	6.90	6.90	6.90	6.90	6.90	6.90	6.90
$CAL=BOS	14.34	15.26	16.32	14.98	14.98	14.98	14.98
$CAL=NEW	14.19	15.11	16.17	14.83	14.83	14.83	14.83
$CAL=NOR	14.09	15.01	16.07	14.73	14.73	14.73	14.73
$CAL3CHI	17.67	16.73	19.00	16.10	16.10	16.10	16.10
$CAL=MEM	24.16	20.49	23.16	20.26	20.26	20.26	20.26
$CAL3OMA	15.91	17.98	20.85	20.83	20.83	20.83	20.83
$CAL=SEA	12.19	13.45	14.91	14.03	14.36	14.73	15.13
$CAL=LAN	11.41	12.33	13.39	12.05	12.05	12.05	12.05
$CAL=TAM	13.71	14.63	15.69	14.35	14.35	14.35	14.35
$CAL3ROT	16.16	17.08	18.14	16.80	16.80	16.80	16.80
$CHI=NEW				10.20	10.20	10.20	10.20
$CHI=NOR				9.69	9.69	9.69	9.69
$CHI=MEM				2.16	2.16	2.16	2.16
$CHI=TAM				6.01	6.01	6.01	6.01
$CHI=ROT				10.61	10.61	10.61	10.61
*TUC5LAN	35.19	38.77	42.01	43.79	48.29	50.70	53.24
*SUD6NEW	17.44	19.03	20.38	21.33	23.41	24.51	25.67
*SUD6CHI	20.20	22.12	23.72	25.46	27.26	28.58	29.96
*SUD6ROT	37.58	39.17	40.45	41.37	43.37	44.43	45.53
$NEW=NOR						1.80	1.80
$NEW=ROT						6.90	6.90
$MEM=TAM						3.96	3.96
$MEM=ROT						8.45	8.45
$FRI=SEA						5.24	5.24

APPENDIX 7

TABLE 2E - ACID EQUIVALENT FILE

	A	B	C	D	E	F	G
*TUCSON	6.85	6.85	27.42	27.42	27.42	27.42	27.42
*SUDBURY	6.85	6.85	27.42	27.42	27.42	27.42	27.42

APPENDIX 7

TABLE 3

SAMPLE LISTING FROM PROGRAM RRB 16 (DEMAND)

```
                         SUPPLY CARDS--CASE 1980F                              1

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

 FR 1980F     COST
 UB 1980F     *TUCSON       0.20
 UB 1980F     $ORLEANS      4.50
 UB 1980F     $COATMEX      0.50
 UB 1980F     $ARUBA        1.10
 UB 1980F     $CALGARY      8.00
 UB 1980F     *SUDBURY      0.90
 UB 1980F     $CHICAGO      0.00
 UB 1980F     $NEWARK       0.00
 UB 1980F     $MEMPHIS      0.00
 UB 1980F     $FRISCO       0.00
```

APPENDIX 7

TABLE 4

SAMPLE LISTING FROM PROGRAM RRB 16 (SUPPLY)

```
                          DEMAND CARDS--CASE 1980F                             1
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

 FX 1980F     =BOSTON       0.01
 LB 1980F     1BOSTON       0.00
 LB 1980F     2BOSTON       0.00
 FX 1980F     =NEWARK       0.01
 LB 1980F     1NEWARK       0.00
 LB 1980F     2NEWARK       0.00
 UB 1980F     6NEWARK       0.01
 FX 1980F     =NORFOLK      0.41
 LB 1980F     1NORFOLK      0.20
 LB 1980F     2NORFOLK      0.00
 FX 1980F     =CHICAGO      0.01
 LB 1980F     3CHICAGO      0.00
 UB 1980F     6CHICAGO      0.01
 FX 1980F     =MEMPHIS      0.00
 FX 1980F     =OMAHA        0.00
 LB 1980F     3OMAHA        0.00
 FX 1980F     =SEATTLE      0.20
 FX 1980F     =LANG.CA      0.14
 UB 1980F     5LANG.CA      0.10
 FX 1980F     =TAMPA        2.97
 LB 1980F     1TAMPA        1.00
 LB 1980F     2TAMPA        0.00
 FX 1980F     =ROTT'DM      1.60
 LB 1980F     1ROTT'DM      0.00
 LB 1980F     2ROTT'DM      0.00
 LB 1980F     3ROTT'DM      0.00
 UB 1980F     6ROTT'DM      0.15
```

APPENDIX 7

TABLE 5

SAMPLE OUTPUT FROM PROGRAM RRB 15

TABLE 5A

```
                            COST CARDS--CASE 1980F
                                                                               1
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    $ORL1BOS  COST         23.66
    $ORL1NEW  COST         22.99
    $ORL1NOR  COST         22.48
    $ORL=CHI  COST         21.21
    $ORL=MEM  COST         19.05
    $ORL=OMA  COST         21.51
    $ORL1TAM  COST         18.80
    $ORL1ROT  COST         23.40
    $COA2BOS  COST         23.04
    $COA2NEW  COST         22.77
    $COA2NOR  COST         22.56
    $COA2TAM  COST         21.62
    $COA2ROT  COST         26.67
    $ARU=BOS  COST         19.28
    $ARU=NEW  COST         19.03
    $ARU=NOR  COST         18.84
    $ARU=TAM  COST         18.65
    $ARU=ROT  COST         21.90
    $CAL=BOS  COST         20.26
    $CAL=NEW  COST         20.11
    $CAL=NOR  COST         20.01
    $CAL3CHI  COST         21.73
    $CAL=MEM  COST         25.49
    $CAL3OMA  COST         22.98
    $CAL=SEA  COST         18.45
    $CAL=LAN  COST         17.33
    $CAL=TAM  COST         19.63
    $CAL3ROT  COST         22.08
    $CHI=NEW  COST          0.00
    $CHI=NOR  COST          0.00
    $CHI=MEM  COST          0.00
    $CHI=TAM  COST          0.00
    $CHI=ROT  COST          0.00
    *TUC5LAN  COST         31.92
    *SUD6NEW  COST         25.87
    *SUD6CHI  COST         28.96
    *SUD6ROT  COST         46.01
    $NEW=NOR  COST          0.00
    $NEW=ROT  COST         -0.00
    $MEM=TAM  COST         -0.00
    $MEM=ROT  COST         -0.00
    $FRI=SEA  COST         -0.00
```

APPENDIX 7

TABLE 5B

SAMPLE PRINT-OUT FROM PROGRAM RRB 15

```
                     MINIMUM          TRANSPORTATION     MINIMUM
TRADE LINK          FOB PRICE              COST       DELIVERED PRICE


$ORL1BOS              17.00                6.66            23.66
$ORL1NEW              17.00                5.99            22.99
$ORL1NOR              17.00                5.48            22.48
$ORL CHI              17.00                4.21            21.21
$ORL MEM              17.00                2.05            19.05
$ORL OMA              17.00                4.51            21.51
$ORL1TAM              17.00                1.80            18.80
$ORL1ROT              17.00                6.40            23.40
$COA2BOS              20.00                3.04            23.04
$COA2NEW              20.00                2.77            22.77
$COA2NOR              20.00                2.56            22.56
$COA2TAM              20.00                1.62            21.62
$COA2ROT              20.00                6.67            26.67
$ARU BOS              15.00                4.28            19.28
$ARU NEW              15.00                4.03            19.03
$ARU NOR              15.00                3.94            18.94
$ARU TAM              15.00                3.65            18.65
$ARU ROT              15.00                6.90            21.90
$CAL BOS               5.00               15.26            20.26
$CAL NEW               5.00               15.11            20.11
$CAL NOR               5.00               15.01            20.01
$CAL3CHI               5.00               16.73            21.73
$CAL MEM               5.00               20.49            25.49
$CAL3OMA               5.00               17.98            22.98
$CAL SEA               5.00               13.45            18.45
$CAL LAN               5.00               12.33            17.33
$CAL TAM               5.00               14.63            19.63
$CAL3ROT               5.00               17.08            22.08
$CHI NEW               0.00                0.00             0.00
$CHI NOR               0.00                0.00             0.00
$CHI MEM               0.00                0.00             0.00
$CHI TAM               0.00                0.00             0.00
$CHI ROT               0.00                0.00             0.00
*TUC5LAN               0.01               38.77            31.92
*SUD6NEW              13.70               19.03            25.87
*SUD6CHI              13.70               22.12            26.96
*SUD6ROT              13.70               39.17            46.01
$NEW NOR              -0.00                0.00             0.00
$NEW ROT              -0.00                0.00            -0.00
$MEM TAM              -0.00                0.00            -0.00
$MEM ROT              -0.00                0.00            -0.00
$ERI SEA              -0.00                0.00            -0.00
```

APPENDIX 7 - TABLE 6

SAMPLE OF LP-MOSS INPUT DECK

```
                      INPUT DECK TO LP-MOSS PROGRAM--CASE 1980F                            1

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

// XEQ MOSS
INPUT
NAME          1980F
    $CHI=NEW  $CHICAGO        1.           (ACTIVITY CARDS)
    $CHI=NEW  =NEWARK         1.
    $CHI=NOR  $CHICAGO        1.
    $CHI=NOR  =NORFOLK        1.
    $CHI=MEM  $CHICAGO        1.
    $CHI=MEM  =MEMPHIS        1.
    $CHI=TAM  $CHICAGO        1.
    $CHI=TAM  =TAMPA          1.
    $CHI=ROT  $CHICAGO        1.
    $CHI=ROT  =ROTT'DM        1.
    $ORL1BOS  $ORLEANS        1.
    $ORL1BOS  1BOSTON         1.
    $ORL1BOS  =BOSTON         1.
    $ORL1NEW  $ORLEANS        1.
    $ORL1NEW  1NEWARK         1.
    $ORL1NEW  =NEWARK         1.
    $ORL1NOR  $ORLEANS        1.
    $ORL1NOR  1NORFOLK        1.
    $ORL1NOR  =NORFOLK        1.
    $ORL=CHI  $ORLEANS        1.
    $ORL=CHI  =CHICAGO        1.
    $ORL=MEM  $ORLEANS        1.
    $ORL=MEM  =MEMPHIS        1.
    $ORL=OMA  $ORLEANS        1.
    $ORL=OMA  =OMAHA          1.
    $ORL1TAM  $ORLEANS        1.
    $ORL1TAM  1TAMPA          1.
    $ORL1TAM  =TAMPA          1.
    $ORL1ROT  $ORLEANS        1.
    $ORL1ROT  1ROTT'DM        1.
    $ORL1ROT  =ROTT'DM        1.
    $COA2BOS  $COATMEX        1.
    $COA2BOS  2BOSTON         1.
    $COA2BOS  =BOSTON         1.
    $COA2NEW  $COATMEX        1.
    $COA2NEW  2NEWARK         1.
    $COA2NEW  =NEWARK         1.
    $COA2NOR  $COATMEX        1.
    $COA2NOR  2NORFOLK        1.
    $COA2NOR  =NORFOLK        1.
    $COA2ROT  $COATMEX        1.
    $COA2ROT  2ROTT'DM        1.
    $COA2ROT  =ROTT'DM        1.
    $COA2TAM  $COATMEX        1.
    $COA2TAM  2TAMPA          1.
    $COA2TAM  =TAMPA          1.
    $ARU=BOS  $ARUBA          1.
    $ARU=BOS  =BOSTON         1.
    $ARU=NEW  $ARUBA          1.
    $ARU=NEW  =NEWARK         1.
    $ARU=NOR  $ARUBA          1.
    $ARU=NOR  =NORFOLK        1.
```

APPENDIX 7 - TABLE 6 (CONTINUED)

```
                INPUT DECK TO LP-MOSS PROGRAM--CASE 1980F                              2

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    $ARU=TAM  $ARUBA        1.
    $ARU=TAM  =TAMPA        1.
    $ARU=ROT  $ARUBA        1.
    $ARU=ROT  =ROTT'DM      1.
    $CAL=BOS  $CALGARY      1.
    $CAL=BOS  =BOSTON       1.
    $CAL=NEW  $CALGARY      1.
    $CAL=NEW  =NEWARK       1.
    $CAL=NOR  $CALGARY      1.
    $CAL=NOR  =NORFOLK      1.
    $CAL=MEM  $CALGARY      1.
    $CAL=MEM  =MEMPHIS      1.
    $CAL=SEA  $CALGARY      1.
    $CAL=SEA  =SEATTLE      1.
    $CAL=LAN  $CALGARY      1.
    $CAL=LAN  =LANG.CA      1.
    $CAL3ROT  $CALGARY      1.
    $CAL3ROT  3ROTT'DM      1.
    $CAL3ROT  =ROTT'DM      1.
    $CAL=TAM  $CALGARY      1.
    $CAL=TAM  =TAMPA        1.
    $CAL3CHI  $CALGARY      1.
    $CAL3CHI  3CHICAGO      1.
    $CAL3CHI  =CHICAGO      1.
    $CAL3OMA  $CALGARY      1.
    $CAL3OMA  3OMAHA        1.
    $CAL3OMA  =OMAHA        1.
    *SUD6NEW  *SUDBURY      1.
    *SUD6NEW  6NEWARK       1.
    *SUD6NEW  =NEWARK       1.
    *TUC5LAN  *TUCSON       1.
    *TUC5LAN  5LANG.CA      1.
    *TUC5LAN  =LANG.CA      1.
    *SUD6CHI  *SUDBURY      1.
    *SUD6CHI  6CHICAGO      1.
    *SUD6CHI  =CHICAGO      1.
    *SUD6ROT  *SUDBURY      1.
    *SUD6ROT  6ROTT'DM      1.
    *SUD6ROT  =ROTT'DM      1.
    $NEW=NOR  $NEWARK       1.
    $NEW=NOR  =NORFOLK      1.
    $NEW=ROT  $NEWARK       1.
    $NEW=ROT  =ROTT'DM      1.
    $MEM=TAM  $MEMPHIS      1.
    $MEM=TAM  =TAMPA        1.
    $MEM=ROT  $MEMPHIS      1.
    $MEM=ROT  =ROTT'DM      1.
    $FRI=SEA  $FRISCO       1.
    $FRI=SEA  =SEATTLE      1.
    $ORL1BOS  COST        23.65      (COST CARDS PREPARED BY RRB 15)
    $ORL1NEW  COST        22.99
    $ORL1NOR  COST        22.48
    $ORL=CHI  COST        21.21
    $ORL=MEM  COST        19.05
    $ORL=OMA  COST        21.51
```

APPENDIX 7 - TABLE 6 (CONTINUED)

```
                 INPUT DECK TO LP-MOSS PROGRAM--CASE 1980F                     3

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    $ORL1TAM  COST         18.80
    $ORL1ROT  COST         23.40
    $COA2BOS  COST         23.04
    $COA2NEW  COST         22.77
    $COA2NOR  COST         22.56
    $COA2TAM  COST         21.62
    $COA2ROT  COST         26.67
    $ARU=BOS  COST         19.28
    $ARU=NEW  COST         19.03
    $ARU=NOR  COST         18.84
    $ARU=TAM  COST         18.65
    $ARU=ROT  COST         21.90
    $CAL=BOS  COST         20.26
    $CAL=NEW  COST         20.11
    $CAL=NOR  COST         20.01
    $CAL3CHI  COST         21.73
    $CAL=MEM  COST         25.49
    $CAL3OMA  COST         22.98
    $CAL=SEA  COST         18.45
    $CAL=LAN  COST         17.33
    $CAL=TAM  COST         19.63
    $CAL3ROT  COST         22.08
    $CHI=NEW  COST          0.00
    $CHI=NOR  COST          0.00
    $CHI=MEM  COST          0.00
    $CHI=TAM  COST          0.00
    $CHI=ROT  COST          0.00
    *TUC5LAN  COST         31.92
    *SUD6NEW  COST         25.87
    *SUD6CHI  COST         28.96
    *SUD6ROT  COST         46.01
    $NEW=NOR  COST          0.00
    $NEW=ROT  COST         -0.00
    $MEM=TAM  COST         -0.00
    $MEM=ROT  COST         -0.00
    $FRI=SEA  COST         -0.00
FX 1980F     =BOSTON        0.01    (DEMAND CARDS PREPARED BY RRB 16)
LB 1980F     1BOSTON        0.00
LB 1980F     2BOSTON        0.00
FX 1980F     =NEWARK        0.01
LB 1980F     1NEWARK        0.00
LB 1980F     2NEWARK        0.00
UB 1980F     6NEWARK        0.01
FX 1980F     =NORFOLK       0.41
LB 1980F     1NORFOLK       0.20
LB 1980F     2NORFOLK       0.00
FX 1980F     =CHICAGO       0.01
LB 1980F     3CHICAGO       0.00
UB 1980F     6CHICAGO       0.01
FX 1980F     =MEMPHIS       0.00
FX 1980F     =OMAHA         0.00
LB 1980F     3OMAHA         0.00
FX 1980F     =SEATTLE       0.20
FX 1980F     =LANG.CA       0.14
UB 1980F     5LANG.CA       0.10
```

APPENDIX 7 - TABLE 6 (CONTINUED)

INPUT DECK TO LP-MOSS PROGRAM--CASE 1980F

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  FX 1980F       =TAMPA        2.97
  LB 1980F       1TAMPA        1.00
  LB 1980F       2TAMPA        0.00
  FX 1980F       =ROTT'DM      1.60
  LB 1980F       1ROTT'DM      0.00
  LB 1980F       2ROTT'DM      0.00
  LB 1980F       3ROTT'DM      0.00
  UB 1980F       6ROTT'DM      0.15
  FR 1980F       COST
  UB 1980F       *TUCSON       0.20          (SUPPLY CARDS PREPARED BY RRB 16)
  UB 1980F       $ORLEANS      4.50
  UB 1980F       $COATMEX      0.50
  UB 1980F       $ARUBA        1.10
  UB 1980F       $CALGARY      8.00
  UB 1980F       *SUDBURY      0.90
  UB 1980F       $CHICAGO      0.00
  UB 1980F       $NEWARK       0.00
  UB 1980F       $MEMPHIS      0.00
  UB 1980F       $FRISCO       0.00
ENDATA
MOVE
    PUNCH        PRINTER
    DATA         1980F
ENDATA
BCDOUT
MOVE
    DATA         1980F
    BOUNDS       1980F
    MINIMIZE     COST
    REPORT       CARD
ENDATA
LPSOLUTION

     (BLANK CARDS FOR PUNCHING)

END
```

APPENDIX 7 - TABLE 7

SAMPLE OUTPUT FROM LP-MOSS

```
               OUTPUT CARDS FROM LP-MOSS PROGRAM--CASE 1980F                   1

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

 $CHI=NEWLL   3        0.000************       0.000       0.000      -2.870
 $CHICAGOEQ   0        0.000       0.000       0.000       0.000      22.080
 =NEWARK EQ   0        0.010       0.010       0.010       0.000     -19.209
 $CHI=NORLL   3        0.000************       0.000       0.000      -3.060
 =NORFOLKEQ   0        0.410       0.410       0.410       0.000     -19.020
 $CHI=MEMLL   3        0.000************       0.000       0.000     -22.080
 =MEMPHISB*   0        0.000       0.000       0.000       0.000       0.000
 $CHI=TAMLL   3        0.000************       0.000       0.000      -3.280
 =TAMPA  EQ   0        2.970       2.970       2.970       0.000     -18.800
 $CHI=ROTB*   3        0.000************       0.000       0.000       0.000
 =ROTT'DMEQ   0        1.600       1.600       1.600       0.000     -22.080
 $ORL1BOSLL   4        0.000************       0.000      23.660      -4.199
 $ORLEANSB*   0        3.180       4.500       0.000       0.000       0.000
 1BOSTON B*   0        0.000************       0.000       0.000       0.000
 =BOSTON EQ   0        0.010       0.010       0.010       0.000     -19.460
 $ORL1NEWLL   4        0.000************       0.000      22.990      -3.780
 1NEWARK B*   0        0.000************       0.000       0.000       0.000
 $ORL1NORB*   4        0.199************       0.000      22.479       0.000
 1NORFOLKLL   0        0.200************       0.200       0.000      -3.460
 $ORL=CHIB*   3        0.010************       0.000      21.210       0.000
 =CHICAGOEQ   0        0.010       0.010       0.010       0.000     -21.210
 $ORL=MEMLL   3        0.000************       0.000      19.049     -19.049
 $ORL=OMALL   3        0.000************       0.000      21.510     -21.510
 =OMAHA  B*   0        0.000       0.000       0.000       0.000       0.000
 $ORL1TAMB*   4        2.970************       0.000      18.800       0.000
 1TAMPA  B*   0        2.970************       1.000       0.000       0.000
 $ORL1ROTLL   4        0.000************       0.000      23.400      -1.319
 1ROTT'DMB*   0        0.000************       0.000       0.000       0.000
 $COA2BOSLL   4        0.000************       0.000      23.040      -3.579
 $COATMEXB*   0        0.000       0.500       0.000       0.000       0.000
 2BOSTON B*   0        0.000************       0.000       0.000       0.000
 $COA2NEWLL   4        0.000************       0.000      22.770      -3.560
 2NEWARK B*   0        0.000************       0.000       0.000       0.000
 $COA2NORLL   4        0.000************       0.000      22.559      -3.540
 2NORFOLKB*   0        0.000************       0.000       0.000       0.000
 $COA2ROTLL   4        0.000************       0.000      26.670      -4.589
 2ROTT'DMB*   0        0.000************       0.000       0.000       0.000
 $COA2TAMLL   4        0.000************       0.000      21.619      -2.819
 2TAMPA  B*   0        0.000************       0.000       0.000       0.000
 $ARU=BOSB*   3        0.010************       0.000      19.280       0.000
 $ARUBA  UL   0        1.100       1.100       0.000       0.000      -0.180
 $ARU=NEWB*   3        0.010************       0.000      19.029       0.000
 $ARU=NORB*   3        0.210************       0.000      18.839       0.000
 $ARU=TAMLL   3        0.000************       0.000      18.649      -0.030
 $ARU=ROTB*   3        0.869************       0.000      21.900       0.000
 $CAL=BOSLL   3        0.000************       0.000      20.260      -0.799
 $CALGARYB*   0        1.070       8.000       0.000       0.000       0.000
 $CAL=NEWLL   3        0.000************       0.000      20.110      -0.900
 $CAL=NORLL   3        0.000************       0.000      20.010      -0.990
 $CAL=MEMLL   3        0.000************       0.000      25.490     -25.490
 $CAL=SEAB*   3        0.199************       0.000      18.450       0.000
 =SEATTLEEQ   0        0.200       0.200       0.200       0.000     -18.449
 $CAL=LANB*   3        0.140************       0.000      17.330       0.000
 =LANG.CAEQ   0        0.140       0.140       0.140       0.000     -17.330
 $CAL3ROTB*   4        0.730************       0.000      22.080       0.000
```

APPENDIX 7 - TABLE 7 (CONTINUED)

```
                  OUTPUT CARDS FROM LP-MOSS PROGRAM--CASE 1980F                 2

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

 3ROTT'DMB*   0        0.730 ***********       0.000       0.000       0.000
 $CAL=TAMLL   3        0.000 ***********       0.000      19.630      -0.830
 $CAL3CHILL   4        0.000 ***********       0.000      21.729      -0.519
 3CHICAGOB*   0        0.000 ***********       0.000       0.000       0.000
 $CAL3OMALL   4        0.000 ***********       0.000      22.979     -22.980
 3OMAHA  B*   0        0.000 ***********       0.000       0.000       0.000
 *SUD6NEWB*   4        0.000 ***********       0.000      25.870       0.000
 *SUDBURYLL   0        0.000       0.900       0.000       0.000      -6.660
 6NEWARK B*   0        0.000       0.010       0.000       0.000       0.000
 *TUC5LANLL   4        0.000 ***********       0.000      31.920     -14.590
 *TUCSON B*   0        0.000       0.200       0.000       0.000       0.000
 5LANG.CAB*   0        0.000       0.100       0.000       0.000       0.000
 *SUD6CHILL   4        0.000 ***********       0.000      28.960      -1.089
 6CHICAGOB*   0        0.000       0.010       0.000       0.000       0.000
 *SUD6ROTLL   4        0.000 ***********       0.000      46.010     -17.270
 6ROTT'DMB*   0        0.000       0.150       0.000       0.000       0.000
 $NEW=NORLL   3        0.000 ***********       0.000       0.000      -3.060
 $NEWARK EQ   0        0.000       0.000       0.000       0.000      22.080
 $NEW=ROTB*   3        0.000 ***********       0.000       0.000       0.000
 $MEM=TAMLL   3        0.000 ***********       0.000       0.000      -3.280
 $MEMPHISEQ   0        0.000       0.000       0.000       0.000      22.080
 $MEM=ROTB*   3        0.000 ***********       0.000       0.000       0.000
 $FRI=SEAB*   3        0.000 ***********       0.000       0.000       0.000
 $FRISCO EQ   0        0.000       0.000       0.000       0.000      18.449
 COST    B*   0      106.171 *********** ***********      -1.000       1.000
```

APPENDIX 7 - TABLE 8

```
                EXECUTION DECK FOR PROGRAM RRB07--CASE 1980F                   1

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

// XEQ RRB07     4
*FILES(5,MFC80)
*FILES(2,MFP80)
*FILES(3,MFG80)
*FILES(4,MFN80)
         06
 $CHI=NEWLL   3        0.000 ***********       0.000       0.000      -2.870
 $CHICAGOEQ   0        0.000       0.000       0.000       0.000      22.080
 =NEWARK EQ   0        0.010       0.010       0.010       0.000     -19.209
 $CHI=NORLL   3        0.000 ***********       0.000       0.000      -3.060
 =NORFOLKEQ   0        0.410       0.410       0.410       0.000     -19.020
 $CHI=MEMLL   3        0.000 ***********       0.000       0.000     -22.080
 =MEMPHISB*   0        0.000       0.000       0.000       0.000       0.000
 $CHI=TAMLL   3        0.000 ***********       0.000       0.000      -3.280
 =TAMPA  EQ   0        2.970       2.970       2.970       0.000     -18.800
 $CHI=ROTB*   3        0.000 ***********       0.000       0.000       0.000
 =ROTT'DMEQ   0        1.600       1.600       1.600       0.000     -22.080
 $ORL1BOSLL   4        0.000 ***********       0.000      23.660      -4.199
 $ORLEANSB*   0        3.180       4.500       0.000       0.000       0.000
 1BOSTON B*   0        0.000 ***********       0.000       0.000       0.000
 =BOSTON EQ   0        0.010       0.010       0.010       0.000     -19.460
 $ORL1NEWLL   4        0.000 ***********       0.000      22.990      -3.780
 1NEWARK B*   0        0.000 ***********       0.000       0.000       0.000
 $ORL1NORB*   4        0.199 ***********       0.000      22.479       0.000
 1NORFOLKLL   0        0.200 ***********       0.200       0.000      -3.460
 $ORL=CHIB*   3        0.010 ***********       0.000      21.210       0.000
 =CHICAGOEQ   0        0.010       0.010       0.010       0.000     -21.210
 $ORL=MEMLL   3        0.000 ***********       0.000      19.049     -19.049
 $ORL=OMALL   3        0.000 ***********       0.000      21.510     -21.510
 =OMAHA  B*   0        0.000       0.000       0.000       0.000       0.000
 $ORL1TAMB*   4        2.970 ***********       0.000      18.800       0.000
 1TAMPA  B*   0        2.970 ***********       1.000       0.000       0.000
 $ORL1ROTLL   4        0.000 ***********       0.000      23.400      -1.319
 1ROTT'DMB*   0        0.000 ***********       0.000       0.000       0.000
 $COA2BOSLL   4        0.000 ***********       0.000      23.040      -3.579
 $COATMEXB*   0        0.000       0.500       0.000       0.000       0.000
 2BOSTON B*   0        0.000 ***********       0.000       0.000       0.000
 $COA2NEWLL   4        0.000 ***********       0.000      22.770      -3.560
 2NEWARK B*   0        0.000 ***********       0.000       0.000       0.000
 $COA2NORLL   4        0.000 ***********       0.000      22.559      -3.540
 2NORFOLKB*   0        0.000 ***********       0.000       0.000       0.000
 $COA2ROTLL   4        0.000 ***********       0.000      26.670      -4.589
 2ROTT'DMB*   0        0.000 ***********       0.000       0.000       0.000
 $COA2TAMLL   4        0.000 ***********       0.000      21.619      -2.819
 2TAMPA  B*   0        0.000 ***********       0.000       0.000       0.000
 $ARU=BOSB*   3        0.010 ***********       0.000      19.280       0.000
 $ARUBA  UL   0        1.100       1.100       0.000       0.000      -0.180
 $ARU=NEWB*   3        0.010 ***********       0.000      19.029       0.000
 $ARU=NORB*   3        0.210 ***********       0.000      18.839       0.000
 $ARU=TAMLL   3        0.000 ***********       0.000      18.649      -0.030
 $ARU=ROTB*   3        0.869 ***********       0.000      21.900       0.000
 $CAL=BOSLL   3        0.000 ***********       0.000      20.260      -0.799
 $CALGARYB*   0        1.070       8.000       0.000       0.000       0.000
 $CAL=NEWLL   3        0.000 ***********       0.000      20.110      -0.900
 $CAL=NORLL   3        0.000 ***********       0.000      20.010      -0.990
```

APPENDIX 7 - TABLE 8 (CONTINUED)

```
                   EXECUTION DECK FOR PROGRAM RRB07--CASE 1980F                2

         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

 $CAL=MEMLL   3        0.000 ***********       0.000      25.490     -25.490
 $CAL=SEAB*   3        0.199 ***********       0.000      18.450       0.000
 =SEATTLEEQ   0        0.200       0.200       0.200       0.000     -18.449
 $CAL=LANB*   3        0.140 ***********       0.000      17.330       0.000
 =LANG.CAEQ   0        0.140       0.140       0.140       0.000     -17.330
 $CAL3ROTB*   4        0.730 ***********       0.000      22.080       0.000
 3ROTT'DMB*   0        0.730 ***********       0.000       0.000       0.000
 $CAL=TAMLL   3        0.000 ***********       0.000      19.630      -0.830
 $CAL3CHILL   4        0.000 ***********       0.000      21.729      -0.519
 3CHICAGOB*   0        0.000 ***********       0.000       0.000       0.000
 $CAL3OMALL   4        0.000 ***********       0.000      22.979     -22.980
 3OMAHA  B*   0        0.000 ***********       0.000       0.000       0.000
 *SUD6NEWB*   4        0.000 ***********       0.000      25.870       0.000
 *SUDBURYLL   0        0.000       0.900       0.000       0.000      -6.660
 6NEWARK B*   0        0.000       0.010       0.000       0.000       0.000
 *TUC5LANLL   4        0.000 ***********       0.000      31.920     -14.590
 *TUCSON B*   0        0.000       0.200       0.000       0.000       0.000
 5LANG.CAB*   0        0.000       0.100       0.000       0.000       0.000
 *SUD6CHILL   4        0.000 ***********       0.000      28.960      -1.089
 6CHICAGOB*   0        0.000       0.010       0.000       0.000       0.000
 *SUD6ROTLL   4        0.000 ***********       0.000      46.010     -17.270
 6ROTT'DMB*   0        0.000       0.150       0.000       0.000       0.000
 $NEW=NORLL   3        0.000 ***********       0.000       0.000      -3.060
 $NEWARK EQ   0        0.000       0.000       0.000       0.000      22.080
 $NEW=ROTB*   3        0.000 ***********       0.000       0.000       0.000
 $MEM=TAMLL   3        0.000 ***********       0.000       0.000      -3.280
 $MEMPHISEQ   0        0.000       0.000       0.000       0.000      22.080
 $MEM=ROTB*   3        0.000 ***********       0.000       0.000       0.000
 $FRI=SEAB*   3        0.000 ***********       0.000       0.000       0.000
 $FRISCO EQ   0        0.000       0.000       0.000       0.000      18.449
 COST    B*   0      106.171 *********** ***********      -1.000       1.000

CASE--1980F 10/28/71    1980
```

APPENDIX 7

TABLE 9

MATRIX

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PROBLEM NAME-CASE--1980F 10/28/71
YEAR-1980

DATA OUTPUT FORMATS
                              DEMAND REGION                       SUPPLY REGION
                              ******   *******                    ***************

                                                                  TRANSACTION(MM LONG TONS)
                              TOTAL DEMAND(MM LONG TONS)          DELIVERED VALUE($/TON)
                              CALCULATED TRADING PRICE($/TON)     COST CHANGE REQUIRED TO CAUSE
                                                                  ACTIVITY TO BECOME ACTIVE($/TON)

TOTAL COST THIS PROBLEM     106.171( $ MILLIONS)



DEMAND   ***********************************     SUPPLY REGIONS***************************************
REGIONS

          $CHICAGO  $ORLEANS  $COATMEX  $ARUBA    $CALGARY  $SUDBURY  $TUCSON   $NEWARK   $MEMPHIS  $FRISCO
  NEWARK      0.00  *******   *******       0.01      0.00  *******   *******   *******   *******   *******
    0.01      0.00  *******   *******      19.03     20.11  *******   *******   *******   *******   *******
   19.71     -2.87  *******   *******      -0.00     -0.90  *******   *******   *******   *******   *******

 NORFOLK      0.00  *******   *******       0.21      0.00  *******   *******      0.00   *******   *******
    0.41      0.00  *******   *******      19.84     20.01  *******   *******      0.00   *******   *******
   19.07     -3.06  *******   *******      -0.00     -0.99  *******   *******     -3.06   *******   *******

 MEMPHIS      0.00      0.00  *******   *******       0.00  *******   *******   *******   *******   *******
    0.00      0.00     19.05  *******   *******      25.49  *******   *******   *******   *******   *******
    0.00    -22.08    -19.05  *******   *******     -25.49  *******   *******   *******   *******   *******

   TAMPA      0.00  *******   *******       0.00      0.00  *******   *******   *******      0.00   *******
    2.97      0.00  *******   *******      18.65     19.63  *******   *******   *******      0.00   *******
   18.80     -3.28  *******   *******      -0.03     -0.83  *******   *******   *******     -3.28   *******

  BOTTOM      0.00  *******   *******       0.87  *******   *******   *******      0.00      0.00   *******
    1.60      0.00  *******   *******      21.90  *******   *******   *******      0.00      0.00   *******
   22.08     -0.00  *******   *******      -0.00  *******   *******   *******     -0.00     -0.00   *******

 1BOSTON  *******       0.00  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      23.56  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      -4.19  *******   *******   *******   *******   *******   *******   *******   *******

  BOSTON  *******   *******   *******       0.01      0.00  *******   *******   *******   *******   *******
    0.01  *******   *******   *******      19.78     20.76  *******   *******   *******   *******   *******
   19.46  *******   *******   *******      -0.00     -0.79  *******   *******   *******   *******   *******

 1NEWARK  *******       0.00  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      22.99  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      -3.78  *******   *******   *******   *******   *******   *******   *******   *******

1NORFOLK  *******       0.19  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      22.47  *******   *******   *******   *******   *******   *******   *******   *******
    3.46  *******      -0.00  *******   *******   *******   *******   *******   *******   *******   *******

 CHICAGO  *******       0.01  *******   *******   *******   *******   *******   *******   *******   *******
    0.01  *******      21.21  *******   *******   *******   *******   *******   *******   *******   *******
   21.71  *******      -0.00  *******   *******   *******   *******   *******   *******   *******   *******

   OMAHA  *******       0.00  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      21.51  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******     -21.51  *******   *******   *******   *******   *******   *******   *******   *******

  1TAMPA  *******       2.97  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      18.80  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      -0.00  *******   *******   *******   *******   *******   *******   *******   *******

 1BOTTOM  *******       0.00  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      23.40  *******   *******   *******   *******   *******   *******   *******   *******
    0.00  *******      -1.31  *******   *******   *******   *******   *******   *******   *******   *******
```

APPENDIX 7

TABLE 9 (CONTINUED)

```
2BOSTON     *******  *******     0.00  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    23.04  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    -3.58  *******  *******  *******  *******  *******  *******  *******

2NEWARK     *******  *******     0.00  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    22.77  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    -3.56  *******  *******  *******  *******  *******  *******  *******

2NORFOLK    *******  *******     0.00  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    22.56  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    -3.54  *******  *******  *******  *******  *******  *******  *******

2ROTT'DM    *******  *******     0.00  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    26.67  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    -4.59  *******  *******  *******  *******  *******  *******  *******

2TAMPA      *******  *******     0.00  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    21.62  *******  *******  *******  *******  *******  *******  *******
   0.00     *******  *******    -2.82  *******  *******  *******  *******  *******  *******  *******

SEATTLE     *******  *******  *******  *******     0.19  *******  *******  *******  *******     0.00
   0.20     *******  *******  *******  *******    18.45  *******  *******  *******  *******     0.00
  18.45     *******  *******  *******  *******    -0.00  *******  *******  *******  *******    -0.00

LANG.CA     *******  *******  *******  *******     0.14  *******  *******  *******  *******  *******
   0.14     *******  *******  *******  *******    17.33  *******  *******  *******  *******  *******
  17.33     *******  *******  *******  *******    -0.00  *******  *******  *******  *******  *******

3ROTT'DM    *******  *******  *******  *******     0.73  *******  *******  *******  *******  *******
   0.00     *******  *******  *******  *******    22.08  *******  *******  *******  *******  *******
   0.00     *******  *******  *******  *******    -0.00  *******  *******  *******  *******  *******

3CHICAGO    *******  *******  *******  *******     0.00  *******  *******  *******  *******  *******
   0.00     *******  *******  *******  *******    21.72  *******  *******  *******  *******  *******
   0.00     *******  *******  *******  *******    -0.51  *******  *******  *******  *******  *******

3OMAHA      *******  *******  *******  *******     0.00  *******  *******  *******  *******  *******
   0.00     *******  *******  *******  *******    22.97  *******  *******  *******  *******  *******
   0.00     *******  *******  *******  *******   -22.98  *******  *******  *******  *******  *******

6NEWARK     *******  *******  *******  *******  *******     0.00  *******  *******  *******  *******
   0.01     *******  *******  *******  *******  *******    25.87  *******  *******  *******  *******
   0.00     *******  *******  *******  *******  *******    -0.00  *******  *******  *******  *******

5LANG.CA    *******  *******  *******  *******  *******  *******     0.00  *******  *******  *******
   0.10     *******  *******  *******  *******  *******  *******    31.92  *******  *******  *******
   0.00     *******  *******  *******  *******  *******  *******   -14.50  *******  *******  *******

6CHICAGO    *******  *******  *******  *******  *******     0.00  *******  *******  *******  *******
   0.01     *******  *******  *******  *******  *******    28.96  *******  *******  *******  *******
   0.00     *******  *******  *******  *******  *******    -1.09  *******  *******  *******  *******

6ROTT'DM    *******  *******  *******  *******  *******     0.00  *******  *******  *******  *******
   0.15     *******  *******  *******  *******  *******    46.01  *******  *******  *******  *******
   0.00     *******  *******  *******  *******  *******   -17.27  *******  *******  *******  *******

 TOTALS
SALES          0.00     3.18     0.07     1.10     1.07     0.00     0.00     0.00     0.00     0.00
SUPPLY         0.00     4.50     0.50     1.10     8.00     0.90     0.20     0.00     0.00     0.00
COST FOR    *******    17.00    20.00    15.00     5.00    13.70     0.01     0.00     0.00     0.00
PROFIT      *******     0.00  *******     0.19     0.00  *******  *******  *******  *******  *******
NET-BACK    *******    17.00  *******    15.19     5.00  *******  *******  *******  *******  *******
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APPENDIX 7

TABLE 10

OTHER OUTPUT FILES

```
                         1980 REGIONAL CALCULATED VALUE

                                   10/4/71


                 A          B          C          D          E          F          G
   BOSTON      25.46      *****      22.43      *****      20.93      19.46      22.46
  1BOSTON       3.20      *****       4.23      *****       4.73       0.00       0.00
  2BOSTON       0.00      *****       0.00      *****       0.00       0.00       0.00
   NEWARK      25.21      *****      22.18      *****      20.68      19.21      22.21
  1NEWARK       2.78      *****       3.80      *****       3.80       0.00       0.00
  2NEWARK       0.02      *****       0.76      *****       1.59       0.00       0.00
  6NEWARK       0.00      *****       0.00      *****       0.00       0.00       0.00
   NORFOLK     25.02      *****      21.99      *****      20.49      19.02      22.02
  1NORFOLK      2.46      *****       3.49      *****       3.49       3.45       0.00
  2NORFOLK      0.00      *****       0.75      *****       1.56       0.00       0.00
   CHICAGO     26.21      *****      24.21      *****      22.71      21.21      24.21
  3CHICAGO      1.51      *****       2.01      *****       2.51       0.00       0.51
  6CHICAGO      0.00      *****       0.00      *****       0.00       0.00       0.00
   MEMPHIS     24.05      *****      22.05      *****      20.55       0.00      22.05
   OMAHA       26.51      *****      24.51      *****      23.01       0.00      24.51
  3OMAHA        2.47      *****       2.97      *****       0.00       0.00       0.00
   SEATTLE     24.45      *****      22.95      *****      21.95      18.45      21.45
   LANG.CA     23.33      *****      21.83      *****      20.83      17.33      20.33
  5LANG.CA      0.00      *****       0.00      *****       0.00       0.00       0.00
   TAMPA       23.80      *****      21.80      *****      20.30      18.80      21.80
  1TAMPA        0.00      *****       0.00      *****       0.00       0.00       0.00
   ROTT'DM     28.08      *****      25.05      *****      23.55      22.08      25.08
  1ROTT'DM      0.32      *****       1.35      *****       1.35       0.00       0.00
  2ROTT'DM      1.05      *****       1.79      *****       2.62       0.00       0.00
  3ROTT'DM      0.00      *****       1.53      *****       2.03       0.00       0.00
  6ROTT'DM      0.00      *****       0.00      *****       0.00       0.00       0.00
```

APPENDIX 7

TABLE 11

OTHER OUTPUT FILES

```
                              1980 CALCULATED EXTRA-REGIONAL SALES

                                         10/4/71

                A          B          C          D          E          F          G
$ORLEANS          5.26     *****       4.58     *****       3.65       3.18       3.06
$COATMEX          0.50     *****       0.50     *****       0.30       0.00       0.00
$ARUBA            1.10     *****       1.10     *****       1.10       1.10       1.10
$CALGARY          1.87     *****       1.16     *****       0.84       1.07       1.73
*TUCSON           0.00     *****       0.00     *****       0.00       0.00       0.00
*SUDBURY          0.00     *****       0.00     *****       0.00       0.00       0.00
$CHICAGO         *****     *****      *****     *****      *****       0.00      *****
```

APPENDIX 7

TABLE 12

OTHER OUTPUT FILES

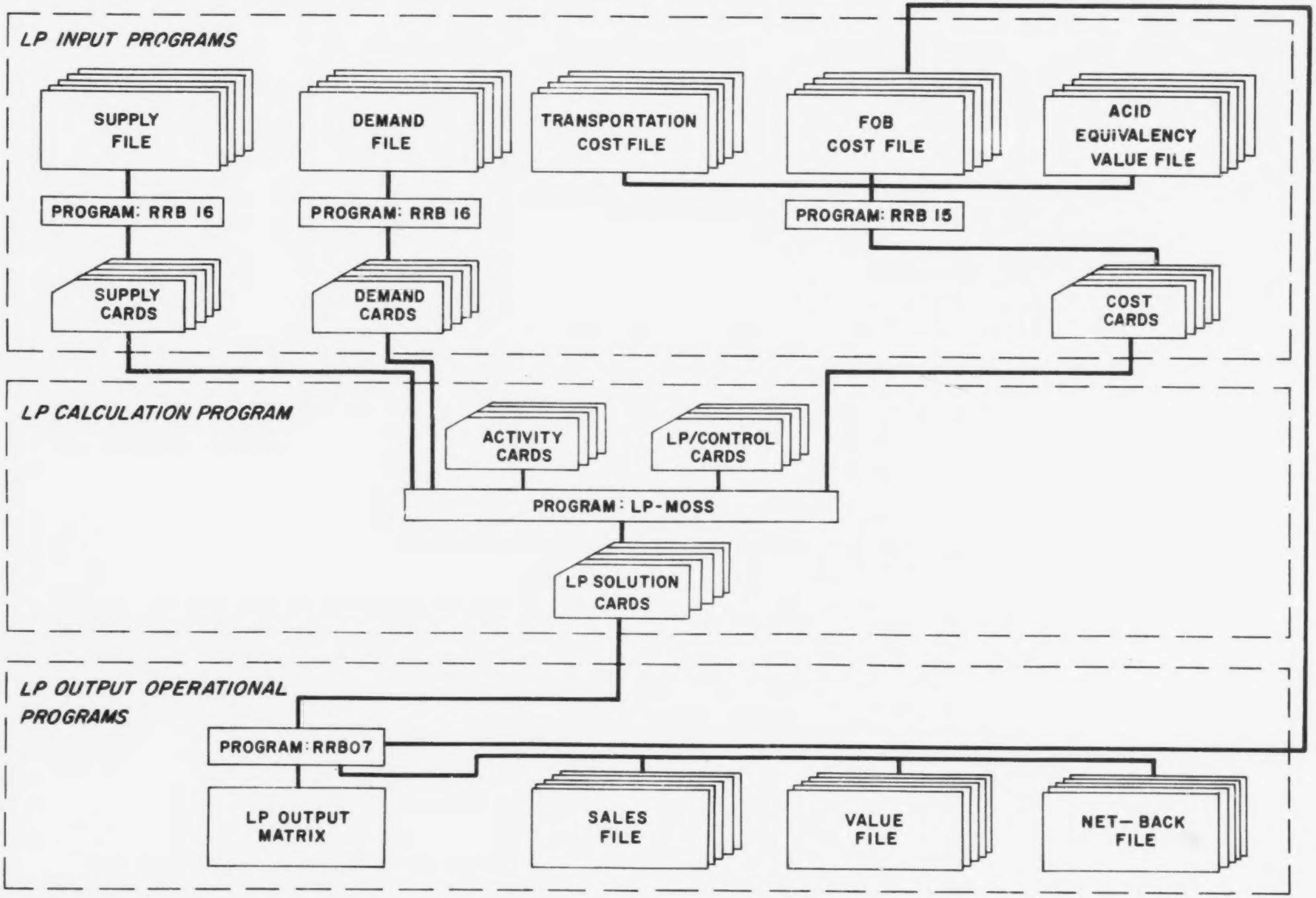
```
                                    1980 CALCULATED NET BACK

                                         10/4/71

                  A          B          C          D          E          F          G
$ORLEANS        22.00      *****      20.00      *****      19.50      17.00      20.00
$COATMEX        22.46      *****      20.18      *****      19.50      *****      *****
$ARUBA          21.18      *****      18.15      *****      16.65      15.18      18.18
$CALGARY        11.00      *****       9.50      *****       8.50       5.00       8.00
*TUCSON         *****      *****      *****      *****      *****      *****      *****
*SUDBURY        *****      *****      *****      *****      *****      *****      *****
$CHICAGO        *****      *****      *****      *****      *****      *****      *****
```

APPENDIX 7

FIGURE I
COMPUTER CALCULATION


LP INPUT PROGRAMS
SUPPLY FILE
DEMAND FILE
TRANSPORTATION COST FILE
FOB COST FILE
ACID EQUIVALENCY VALUE FILE
PROGRAM: RRB 16
PROGRAM: RRB 16
PROGRAM: RRB 15
SUPPLY CARDS
DEMAND CARDS
COST CARDS
LP CALCULATION PROGRAM
ACTIVITY CARDS
LP/CONTROL CARDS
PROGRAM: LP-MOSS
LP SOLUTION CARDS
LP OUTPUT OPERATIONAL PROGRAMS
PROGRAM: RRB07
LP OUTPUT MATRIX
SALES FILE
VALUE FILE
NET-BACK FILE

APPENDIX 8

TEST ON HISTORICAL DATA

A.8.1. Introduction

Before making a large number of computer calculations based on projections of sulfur supply and demand, it was considered necessary to:

- Obtain complete familiarity with the application of the LP program (Appendix 7).
- Demonstrate that the LP program would give reasonable results when applied to historical data.

A.8.2. Basis and Input Data

For test purposes, the Model was simplified from that described in Section 3, e.g. less geographical detail was provided. However, all of the essential elements were included.

The production costs had the following basis:

(1) U.S. Frasch production is represented by low cost, medium cost, and high cost elements all of which are permitted to "trade" in the model. In addition, the stockpile of sulfur in the hands of the U.S. Frasch producers is divided into two parts:

  (a) Stockpile-1 which simulates increments or decrements in production.

  (b) Stockpile-2 which simulates the stock level needed for normal business, including stocks held in liquid terminals, etc.

(2) Mexican Frasch sulfur is assumed to be equivalent to U.S. low cost production because the Mexican deposits were developed by U.S. companies (who would have had no incentive for developing high cost Frasch domes in Mexico).

(3) Western Canadian sulfur, recovered from sour natural gas, is assumed to be offered to the market at operating cost. This is estimated to average about \$6/LT. The latter figure corresponds to the lowest "ex works" price at which Canadian sulfur is offered.*

---

* "Canadian Chemical Processing," p. 20, April 1971.

(4) The stockpile pricing hypothesis is as follows:

(a) U.S. Frasch producers have had two ways of correcting supply/demand imbalances:

Change	Excess Supply	Excess Demand
Production	Reduce	Increase
Price	Reduce	Increase

(b) Production increases or decreases are assumed to affect "Frasch high cost" first.

(c) Under conditions of tight supply, Stockpile-2 (which normally does not "trade") is permitted to offer sulfur at parity with production from gypsum ($40/LT). Stockpile-1 can trade at ("Frasch high cost" + $1/LT).

(d) As supply loosens, we first reach the point at which Stockpile-1 does not trade (because it is the current highest cost supplier except for Stockpile-2) and then the point at which "Frasch high cost" does not trade (i.e., Stockpile-1 volume builds). At this point, Stockpile-1 is allowed to trade at ["Frasch high cost" - $1/LT], and the notional trading price for Stockpile-2 is reduced to ["Frasch high cost" + $1/LT].

(e) The long range implication of reducing the trading price of Stockpile-1 below "Frasch high cost" is that the latter production will be shut down.

(f) If Stockpile-1 still does not trade at ["Frasch high cost" - $1/LT], its permitted trading price is reduced further. For a technical reason (avoidance of "degeneracy" in the LP program) Stockpile-1 is not allowed to trade at "Frasch medium cost" but, in the event of continuing oversupply (i.e., rising Stockpile-1 level), would drop price from ["Frasch medium cost" + $1/LT] to ["Frasch medium cost" - $1/LT].

The full range of the above hypothetical price movements occurred during the period 1960-1970.

Table 1 records price changes for elemental sulfur from 1960 to May, 1971 (on a current dollar basis). Prices were stable during the period 1960 to 1964. An uptrend began in 1965 but did not get into high gear until 1967.

The top part of the table records the average domestic prices for each year from 1960 to 1967. The lower part of the table records prices over shorter time intervals starting in September 1967. It will be seen that U.S. export prices moved up ahead of domestic prices, reflecting the dampening effect of long term contract sales on domestic prices. By the end of 1967, the varying pricing basesreached parity. Some further increases in prices occurred during 1968 topping out at about $42/LT. A small downward adjustment was made in 1969, reflecting a reversal in the stockpile, from a decline in 1968 to a build-up of stocks in 1969. By September 1969, world sulfur prices were in chaos and the U.S. export posting was withdrawn. Domestic posted prices continued for a short time at $40/LT, held up by long term contracts.

By February 1970, U.S. Frasch producers re-established an export posting about $20/LT below that of June 1969. The new $21-22/LT export price is comparable to the Canadian price of $12-13/LT F.O.R. Calgary. However, the latter was still in a downtrend reflecting growing stocks of sulfur recovered from sour natural gas. In consequence, Sulexco switched from a U.S. Gulf to a Rotterdam posting of $27/LT in June 1970, in effect lowering export prices by $1-2/LT. A further price reduction was made by March 1971 in order to meet Canadian competition. The rather wide range of $23.50-26.00/LT ex Rotterdam terminal probably reflects, in part, the abnormally high transportation rates (affecting Canadian exporters) that applied during 1970 (but have subsequently declined to less than normal).

Starting in March, 1971, U.S. Frasch S producers began to post domestic prices on two bases: (a) delivered Chicago and (b) ex Tampa terminal. There is some inconsistency in the present pricing structure in that the ex Rotterdam price is equivalent to an F.O.B. Gulf price of about $19/LT. The latter would be equivalent to slightly lower domestic prices than the postings quoted for Tampa and Chicago. However, the discrepancy amounts to less than $2/LT. Such a differential has existed in the past during periods of excess supply, and is attributable to the marketing strength of the U.S. Frasch S producers in the Tampa/Bartow area.*

Because of price stability from 1960 through 1964, it was decided to omit computer calculations for the years 1961 through 1963. Simple review of the input data showed that the prices calculated for these years would be the same as for 1960.

Input data for supply and demand are given in Tables 2 and 3. Minimum F. O. B. Trading Prices, based on estimates of production costs (on a weighted average basis for the three different categories of U. S. Frasch sulfur) are listed in Table 4. Minimum delivered prices for 1960, incorporating estimated transportation and other delivery costs, are recorded in Table 5. Similar calculations were made for the other years, 1965-1970.

---

*U. S. Frasch sulfur must be competitive with Canadian sulfur at Rotterdam and Chicago, but the Canadian exporters have no terminals at Tampa, and thus cannot compete on equal terms.

A.8.3. Output Data

The results of the computer calculations are shown in Tables 6 and 7. The former lists the netback to each supplier and the quantity of sulfur sold. The latter records the market prices calculated by the computer for each of the demand regions. The data for the U. S. Gulf coast have been plotted in Figure 1 for comparison with actual prices quoted during the test period. In this case, the calculated prices have been plotted with a one year displacement for a reason discussed below.

It will be seen that both U.S. domestic and U.S. export prices are plotted in Figure 1. Since early in 1968, the spread between these two price series has been less than \$2/LT. However in 1967, and many earlier years, the spread was greater. Export prices have tended to be more volatile than domestic prices. Large spreads in price were possible because of the extent to which U.S. Frasch producers used to dominate international trade in elemental sulfur. This is no longer the case because of the rise of Western Canadian exports of recovered sulfur. Because of its "free trade" assumption, the Model does not distinguish between U.S. export and domestic prices. The error in this assumption, unless duties are placed on sulfur imports, is judged not to exceed \$2/LT.

A.8.4. Discussion

The calculated values matched the historical price levels, but anticipated major price changes by about one year. There are two inter-related explanations for this anticipation of price changes:

(a) A considerable amount of U.S. Frasch sulfur is sold on a long term contract basis. During periods of supply/demand imbalance, which bring about changes to spot prices in world markets, the long term contracts delay and dampen price movements in the U.S. markets supplied by the Frasch producers.

(b) Pricing policy for Frasch sulfur reflects what has occurred during the previous year, whereas the Model calculates values based on supply/demand conditions in the current year.

No modification of the Model is needed to make a simple adjustment of one year to the time/value relationship (as was done in Figure 1).

Although the calculations of value tracked historical price movements, it is important to recognize that the Model is not a short range price-prediction tool. This is because substantially different types of data are required for predicting prices a few weeks or months ahead than for making long range projections.

It should also be pointed out that some of the rather small amounts of Frasch high cost production have been used in captive operations. This is a partial explanation of why such production has continued while the Model suggests that it would be curtailed. It is estimated that less than 2% of total production is now in the high cost category and, at this level, does not affect the computer price calculations.

APPENDIX 8

Table 1

Historical Movements of U.S. Frasch Sulfur Prices

	Bright Sulfur, Domestic, Bulk, $/LT	
	Cars, F.O.B. Mines*	Gulf, F.O.B. Vessels *Ø
1960	23.50	25.00
1961	23.50	25.00
1962	23.50	25.00
1963	23.50	25.00
1964	24.50	25.00
1965	26.50	25.50
1966	26.75	28.25
1967	34.25	34.25

* Mean of high and low prices quoted during year

Ø For U.S. and Canadian destinations.

		Gulf, F.O.B. Vessels for Export		Mexican Sulfur F.O.B. Coatzocoalcos
9/25/67	33.50	39.00	33.50	35.00
12/25/67	39.00	39.00	39.00	38.00
3/25/68	42.00	41.00	42.00	--
6/24/68	42.00	41.00	42.00	--
9/30/68	42.00	41.00	42.00	--
12/30/68	42.00	41.00	42.00	--
2/3/69	40.00	41.00	40.00	--
3/31/69	40.00	41.00	40.00	
				W. Canadian Sulfur F.O.R. Alberta, for delivery to U.S.
6/30/69	40.00	41.00	40.00	
9/29/69	40.00	no price quoted	40.00	
12/29/70	--------------no prices quoted ---------			
1/26/70	"	"	"	
2/23/70	NPQ	21-22	NPQ	12-13
3/30/70	"	"	"	"
		ex Rotterdam terminal		
6/29/70		27		11-12
9/28/70		27		10-12
12/28/70		27		10-12
	del. Chicago		ex Tampa terminal	
2/1/71	NPQ	27	NPQ	9-10
3/1/71	26.25-27.25	23.50-26.00	27.00	9-10
3/29/71	26.25-27.25	23.50-26.00	25.00	9-10
5/3/71	26.25-27.25	23.50-26.00	25.00	9-10

APPENDIX 8

Table 2

Sulfur Supply Data for Historical Test of N. Am. Model (10^6 LT of S)

Supplier*	1960	1965	1966	1967	1968	1969	1970E
Frasch - low **	3.76	5.34	6.21	6.13	5.89	5.64	6.15
- medium **	0.66	0.44	0.56	0.59	1.31	1.16	0.89
- high **	0.52	0.34	0.26	0.35	0.35	0.40	0.16
Stockpile - 1 ***	1.75	2.03	1.23	0.50	0.01	0.59	1.26
- 2 ***	2.20	2.20	2.20	2.20	1.95	2.20	2.20
Mexico	0.91	1.33	1.15	1.23	1.23	0.99	0.72
Canada	0.13	0.75	0.75	0.80	0.87	1.07	1.40

---

* Restricted to suppliers active in the North American Model

** "Low", "Medium", "High" refer to estimated production costs

*** The stockpile of U.S. Frasch producers is divided into two parts. One part simulates the level of stocks required for normal business operations. The model allows this part of the stockpile to trade (i.e. to be drawn down) but only at a relatively high price. The other part of the stockpile simulates the mechanism by which Frasch producers have been able to maintain, or restore, a balance between supply and demand. For example, during periods of rising stocks and falling prices, the value of the second stockpile is reduced progressively. The lowered price makes U. S. Frasch sulfur more competitive while, eventually, inducing reduced production of higher cost Frasch sulfur.

Note: Complete data for 1970 were not available at the time the computer tests were made and were partially estimated.

APPENDIX 8

Table 3

Sulfur Demand Data for Historical Test of N. Am. Model

(Millions of Long Tons of S Equivalent)

Demand Region*	1960	1965	1966	1967	1968	1969	1970 E
U.S. - East Coast	1.20	1.39	1.48	1.56	1.58	1.46	1.52
- Florida	0.72	1.56	2.19	2.37	2.15	2.11	2.23
- Gulf Coast	0.26	0.38	0.66	0.63	0.58	0.64	0.72
- Midwest	1.64	2.01	2.13	2.14	1.99	2.02	2.09
- West Coast	0.24	0.39	0.45	0.46	0.41	0.42	0.44
W. Europe	1.09	1.81	1.58	1.59	1.47	1.49	1.36
U.S. Exports	1.00	1.46	1.14	1.01	0.63	0.45	0.38

---

* Restricted to regions active in the North American Model

Notes: (1) For the historical test, all U. S. recovered S values have been netted out of the individual U. S. demand regions.

(2) Complete data for 1970 were not available at the time the computer tests were made, and were partially estimated.

APPENDIX 8

Table 4

Minimum F.O.B. Trading Prices* Calculated for Each Supplier
Active in the Historical Test of the N. Am. Model
(Dollars Per LT of Elemental S)

Supplier	1960	1965	1966	1967	1968	1969	1970
Frasch - Low	15	15	15	15	15	15	15
- Medium	20	20	20	20	20	20	20
- High	25	25	25	25	25	25	25
Stockpile - 1	26	26	26	26	26	21	19
- 2	40	40	40	40	40	26	26
Mexico	15	15	15	15	15	15	15
Canada	6	6	6	6	6	6	6

---

* The "Minimum F.O.B. Trading Prices" are estimates of breakeven production costs except in the case of the Frasch stockpiles, where prices reflect a revaluation of inventory based on a combination of price and stock trends.

APPENDIX 8

Table 5

Minimum Delivered Trading Prices* from Each Supplier To Each Demand Region Active in the 1960 Test Of the N. Am. Model (Dollars Per LT of Elemental S)

	U.S. Frasch Producers						
	Low	Med.	High	Stockpile 1	Stockpile 2	Mexico	Canada
U.S. - East Coast	22.20	27.20	32.20	33.20	47.20	17.91	--
- Florida	18.89	23.89	28.89	29.89	43.89	17.49	--
- Gulf Coast	16.00	21.00	26.00	27.00	41.00	17.34	--
- Midwest	25.35	30.35	35.35	36.35	50.35	24.65	20.00
- West Coast	29.90	34.90	39.90	40.90	54.90	18.66	12.95
W. Europe	19.49	24.49	29.49	30.49	44.49	19.52	18.78
U.S. Exports	15.00	20.00	25.00	26.00	40.00	--	--

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* The minimum delivered trading price is the minimum F.O.B. trading price (Table 4) plus all transportation and terminalling costs to delivery point.

APPENDIX 8

Table 6

Netback to Suppliers Active in the N. Am. Model (Dollars Per LT of Elemental S)

Supplier	1960	1965	1966	1967	1968	1969	1970
Frasch - Low	26.00	26.00	26.00	40.00	20.00	20.00	19.00
- Medium	26.00	26.00	26.00	40.00	20.00	20.00	No Sales
- High	26.00	26.00	26.00	40.00	No sales	No sales	No Sales
Stockpile - 1	26.00	26.00	26.00	40.00	No sales	No sales	19.00
- 2	No sales	No sales	No sales	40.00	No sales	No sales	No Sales
Mexico	30.29	30.29	30.29	44.29	24.29	22.65	21.65
Canada	27.00	22.35	22.35	36.35	16.35	19.70	7.73
• Sales Volumes, Million LT							
Frasch - Low	3.76	5.34	6.21	6.13	5.89	5.64	6.15
- Medium	0.66	0.44	0.56	0.59	0.82	0.89	Nil
- High	0.52	0.34	0.26	0.35	Nil	Nil	Nil
Stockpile - 1	0.17	0.80	0.70	0.50	Nil	Nil	0.47
- 2	Nil	Nil	Nil	0.16	Nil	Nil	Nil
Mexico	0.91	1.33	1.15	1.23	1.23	0.99	0.72
Canada	0.13	0.75	0.75	0.80	0.87	1.07	1.40

APPENDIX 8

Table 7

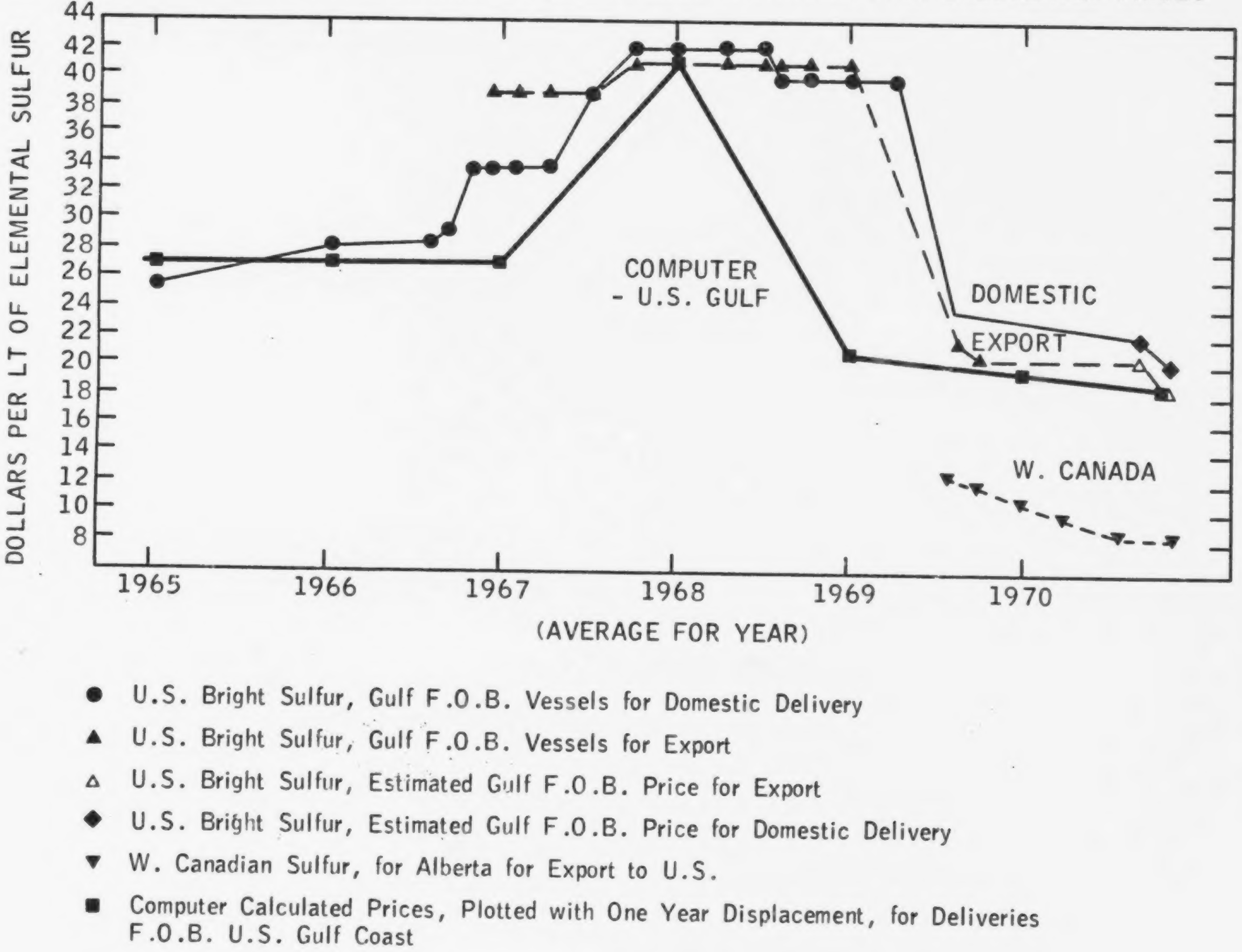
Market Price Calculated By Computer in N. Am. Model (Dollars Per LT of Elemental S)

Demand Region	1960	1965	1966	1967	1968	1969	1970
U.S. - East Coast	33.20	33.20	33.20	47.20	27.20	24.98	23.98
- Florida	29.89	29.89	29.89	43.89	23.89	22.13	21.13
- Gulf Coast	27.00	27.00	27.00	41.00	21.00	20.50	19.50
- Midwest	36.35	36.35	36.35	50.35	30.35	30.40	20.73
- West Coast	29.30	29.30	29.30	43.30	23.30	27.45	17.58
- E. St. Louis	-	-	-	-	-	24.46	23.70
W. Europe	30.49	30.49	30.49	44.49	24.49	25.49	24.49
U.S. Exports	26.00	26.00	26.00	40.00	20.00	20.00	19.00

Appendix 8

Figure 1

COMPARISON OF HISTORICAL PRICE TRENDS WITH COMPUTER CALCULATED PRICES



APPENDIX 9

DELPHI FORECAST

Many of the factors affecting long-range projections are not forecastable in a rigorous way. Current trends may be extrapolated but, if this is done for any appreciable period of time, there is a chance that trend reversals will occur and that the simple type of extrapolation will be invalid. Changes in raw materials sources and technology may well produce trend reversals. However, there is also another factor that will always be of importance in long range projection of business conditions, namely the pace of general economic development. Historical data suggests what the range of possibilities will be, but actual projections are matters of judgment and, thus, of personal bias. Accordingly, the judgment of independent experts was solicited in the form of a Delphi forecast. The "oracles" were drawn from the first rank of Japanese industry, universities and official positions.

The first questionnaire is reproduced in Table 1. Its seventeen questions cover:

- economic activity
    - growth in GNP and population
    - possibility of duties or quotas for sulfur imports

- SO_2 emission control
    - W. Germany
    - Japan

- Technological change
    - nuclear energy
    - new applications for S; changes in S usage

The second questionnaire is reproduced in Table 2. The arithmetic averages of the participants' responses to both questionnaires is included in the table. It is also noted whether convergence of views occurred after the oracles reviewed the summarized (but anonymous) results of the first questionnaire. Convergence was obtained in almost every case.

Two questions, Nos. 6 and 8, that appeared in the first questionnaire were eliminated from the second because a sufficient number of the oracles did not feel qualified to answer them. Two questions, Nos. 16 and 17, were rephrased in order to obtain additional information on expected new uses and technological changes involving sulfur. Question No. 18 was added to the second questionnaire for the same purpose.

Inferences that may be drawn from the Delphi forecast are as follows. The question numbers correspond to those in Table 2.

(1-3) Rates of G.N.P. growth are projected to decline (as has been assumed in our own forecasts). The average rate for the period 1985-2000 is projected to be about 3/4 of that from 1970 to 1985. Declining rates of real economic growth imply parallel declines in the rates of increased demand for fossil fuels, copper, industrial sulfuric acid, etc. In turn, this implies a declining rate of increase for both sulfur recovery and sulfur demand. However, the impact on the latter will eventually be relatively less since it is supported by fertilizer sulfur demand.

(9-10) SO_2 emission controls on fossil fuel combustion are expected to be more stringent in Japan than in W. Germany by 1985. Controls are expected to be tightened further by the year 2000 in both countries.

(11-12) The percentage of S recovered in useful form is expected to be essentially the same (70-80%) in both countries.

(13-15) Growth in nuclear generation of electricity is projected to be extremely rapid in W. Germany, Japan, and the U. S. It is suspected that the Delphi oracles are reflecting concern for continuing economic availability of imported fossil fuels and, thus, are projecting the need to develop nuclear power as quickly as possible. If this occurs, the effect will be to lower the potential for recovered S relative to the case in which a higher proportion of electricity would be generated with fossil fuels.

(16) New applications for sulfur or sulfuric acid might account for as much as 15% of total demand by the year 2000. Almost all of this demand is expected to be in construction materials of various kinds.

(17) Some changes in S demand in existing applications are foreseen. The demand for ammonium sulfate is expected to decrease. This is pertinent (and unfavorable) to systems that would recover AS from utility stack gases or smelters.

(18) Large scale utilization of by-product gypsum is projected as quite probable in Japan. Logistics and industry structure are entirely different in the U. S. Nevertheless, the matter deserves serious consideration. Clearly, if waste gypsum could be converted into a useful product (probably a building material) it would not be a potential pollutant.

A few additional points may be made:

- Nuclear power is expected to develop rapidly. For industrialized countries, half of the energy input to electricity generation is expected to be supplied by atomic power at various times during the 1990's. However, the implication is that, at the turn of the century, fossil fuels will still be supplying much of the energy input to electricity generation (and essentially all of energy input in non-electricity sectors). The further implication is that (the potential for) recovery of sulfur from fossil fuels will be maintained at least through the year 2000. This is a very important point because, theoretically, the ubiquitous use of nuclear power could cause declining use of fossil fuels and, hence, remove the need for abatement sulfur controls. The implication of what the Japanese oracles are projecting is that this theoretical situation will not be achieved until after the year 2000 (and perhaps much later).

- Whereas most of the current demand for sulfur is in the form of acid, "new uses" are likely to be for elemental S in construction materials.

- New uses for S are very unlikely to exceed 15% of total demand by the year 2000; 10% is more likely.

- Japan now has a stockpile of elemental S, recovered from petroleum, of about 1 million tons. In spite of this oversupply, and prospects for its continuance, Japanese production of sulfuric acid from pyrites is expected to decline slowly because the workers' jobs are protected.

- The Japanese economic boom is subsiding. The expansion rate has fallen below 10%/yr.

There are no major differences between the judgments made by the Japanese oracles and those made by the contractor. However, the Delphi forecast can be seen to have provided additional information and insights. The views concerning declining rates of economic development, the timetable for nuclear power, the rather limited prospects for developing new uses for sulfur, and the expectation of being able to utilize waste gypsum are believed to be the most important findings of the Delphi forecast.

APPENDIX 9

TABLE 1

SULFUR MODEL--DELPHI QUESTIONNAIRE NO. 1

Question	Answer	
(A) Economic Activity		
For the countries and time periods specified, what do you expect will be the average, annual, compound, percentage growth in real GNP? (in constant dollars or equivalent)	% Per Year	
(1) EEC (European Economic Community)	1970-1985	1985-2000
(2) Japan		
(3) U.S.A.		
What do you expect the population will be?	Millions in Mid-Year	
(4) U.S.A.	1985	2000
(5) World Total		
What percentage probability do you estimate for the imposition of either a quota or a duty on sulfur imports, before 1935?	% Probability	
(6) EEC	Duty	Quota
(7) Japan		
(8) U.S.A.		
(B) SO_2 Emission Control		
For the countries specified, what percentage of the sulfur present in the fossil fuels consumed during the specified years do you expect will be removed either by processing of the fuel before combustion or by removal of sulfur oxides from combustion gases?	% of S Removed	
(9) German Federal Republic	1985	2000
(10) Japan		

APPENDIX 9

TABLE 1 (cont'd)

Question	Answer	
What percentage of the sulfur that is removed (see questions 9 and 10) do you expect to be recovered in a useful form? (e.g., as elemental S, sulfuric acid, ammonium sulfate, etc., but not as calcium sulfate)	% in Useful Form	
	1985	2000
(11) German Federal Republic		
(12) Japan		
(C) Technological Change		
For the countries specified, in what years do you expect that 25% and 50% of electricity will be generated by nuclear power?	25%	50%
(13) German Federal Republic		
(14) Japan		
(15) U.S.A.		
Can you suggest any new applications for sulfur, or sulfuric acid, that might account for at least 2% of total demand for S by the year 2000? (16)	Nature of Application	
Sulfur, in acid and other forms, is used in a wide variety of applications in the U.S. and other countries. Considering these existing, commercial applications, are there any in which a change in technology either in mode of sulfur usage, or in alternate ways of accomplishing the same result, may increase or decrease the total demand for S by at least 2% by the year 2000? (17)	Nature of Change	

NOTES:

- Please answer all of the questions if possible. However, more limited answers, e.g., for one country or area only, will also be appreciated.
- Although your answers will become part of the feedback in the next questionnaire, these and subsequent answers will not be attributed to you personally.
- If you wish to make any comment whatever, please do so.

APPENDIX 9

TABLE 2

SUMMARIZED RESULTS OF DELPHI QUESTIONNAIRES

(A) Economic Activity

- What do you expect will be the average, annual, compound percentage growth in real GNP?

	% Per Year		Convergence From 1st Round	
	1970-1985	1985-2000		
(1) EEC	4.9 (5.1)	3.6 (3.6)	No change	Yes
(2) Japan	8.3 (8.5)	6.0 (5.4)	No	Yes
(3) U.S.A.	3.6 (3.6)	2.8 (2.9)	No	Yes

- What do you expect the population will be?

	Millions in Mid-Year			
	1985	2000		
(4) U.S.A.	260 (250)	312 (300)	Yes	Yes
(5) World	4810 (4718)	6503 (6109)	Yes	Yes

- What percentage probability do you estimate for the removal of the current import license requirements for sulfur into Japan by 1985 (assuming that a measure of protection will be retained by continuance of import duties)?

	% Probability For Removal Of Import License Requirement	
(7)	79	Yes

Note: First Round results are shown in parentheses.

APPENDIX 9

TABLE 2 (cont'd)

(B) SO_2 Emission Control

- What percentage of the sulfur present in the fossil fuels consumed during the specified years do you expect will be removed either by processing the fuel before combustion or by removal of sulfur oxides from combustion gases?

		% of S Removed		Convergence From 1st Round	
		1985	2000		
(9)	German Fed. Republic	39 (32)	64 (50)	Yes	Yes
(10)	Japan	52 (55)	71 (70)	Yes	Yes

- What percentage of sulfur that is removed (see Questions 9 and 10) do you expect to be recovered in a useful form, e.g., as acid or elemental S but not as $CaSO_4$?

		% in Useful Form			
		1985	2000		
(11)	German Fed. Republic	70 (70)	75 (74)	No Change	Yes
(12)	Japan	78 (77)	81 (81)	Yes	Yes

(C) Technological Change

- In what years do you expect 25% and 50% of electricity will be generated by nuclear power?

		25%	50%		
(13)	German Fed. Republic	1982 (1985)	1997 (3000)	Yes	Yes
(14)	Japan	1985 (1986)	1996 (1998)	Yes	Yes
(15)	U.S.A.	1981 (1981)	1993 (1992)	Yes	Yes

Note: First Round results are shown in parenthesis.

APPENDIX 9

TABLE 2 (cont'd)

(C) Technological Change (Cont'd)

- The following have been suggested as new applications for sulfur or sulfuric acid that might account for at least 2% of total demand for S by the year 2000. What % of total demand would you expect?

			% of Total Demand			% of Total Demand
(16)	(a)	Fillers for plastics	2	(f)	Batteries	Up to 1
	(b)	S-reinforced concrete	2	(g)	S-coated urea	Up to 1
	(c)	Synthetic board	1	(h)	Soil stabilizer	Up to 1
	(d)	Architectural materials	2	(i)	Cheap polymer	--
	(e)	Road pavements (S + asphalt)	3			

- Changes in technology or mode of usage may increase or decrease the total demand for sulfur (in Japan) by at least 2% by the year 2000. What % of total demand would you expect to be contributed by the following?

			% of Total Demand
(17)	(a)	Ammonium sulfate	3
	(b)	Sulfuric acid for treating metal ores	1
	(c)	Sulfuric acid for processing titanium dioxide	1.5
	(d)	Cheap polymers	Up to 1
	(e)	Fertilizers (Except AS)	10

- What percentage probability do you estimate for large scale utilization of by-product calcium sulfate in Japan?

(18) % Probability 57

APPENDIX 10

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